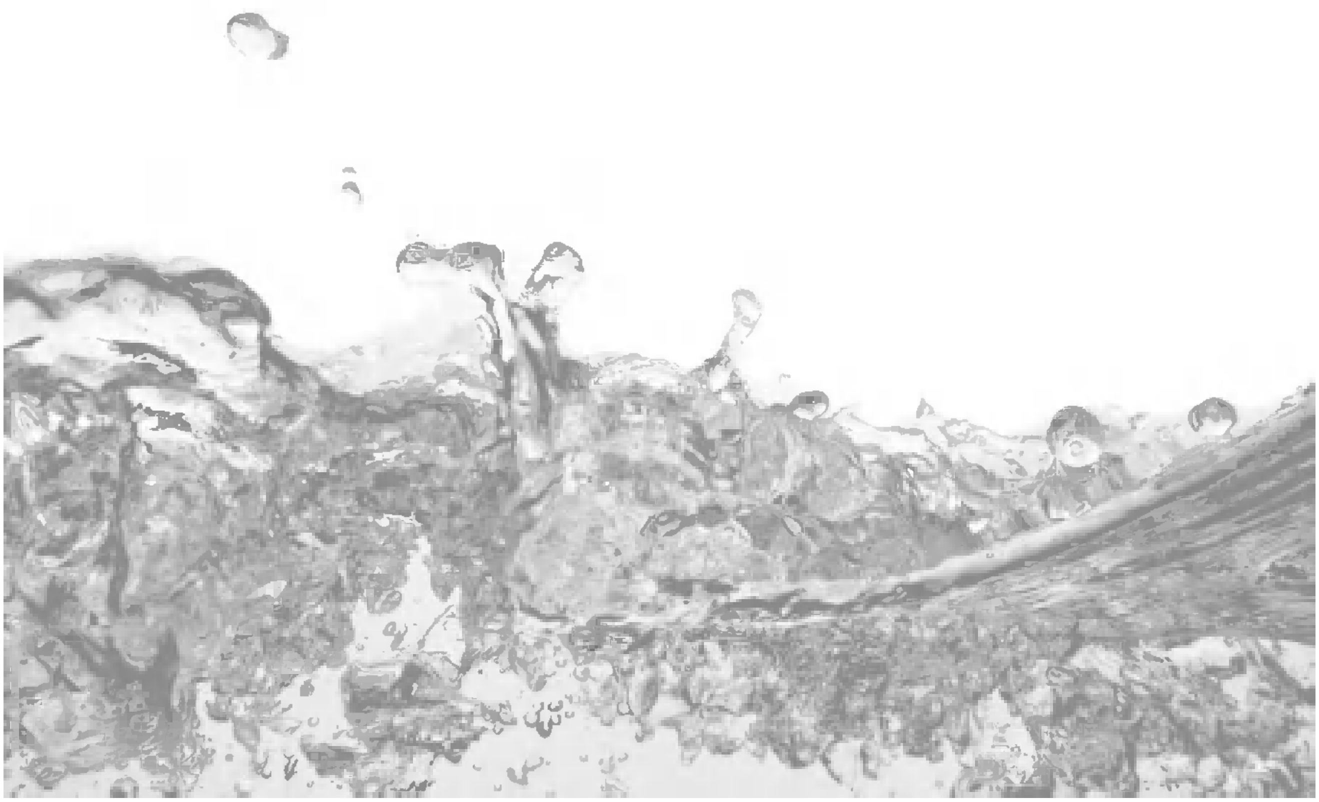
PENNSTATE

COLLEGE OF AGRICULTURAL SCIENCES

A Guide to Private Water Systems in Pennsylvania

A Manual for Rural Homeowners on the Proper Construction and Maintenance of Private Wells, Springs, and Cisterns



Prepared by Stephanie S. Clemens, coordinator, Master Well Owner Network, University of Maryland; Bryan Swistock, water resources extension specialist, Penn State; and William E. Sharpe, professor emeritus, Penn State

This publication was supported by funds provided in part by the Pennsylvania Department of Environmental Protection, the Pennsylvania Ground Water Association, and the Cooperative State Research, Education, and Extension Service Mid-Atlantic Water Program. The opinions and recommendations expressed in this publication do not necessarily reflect those of the funding organizations.

Acknowledgments

Many individuals and agencies deserve credit for the creation of this publication. Among those are each of the funding organizations, which gave us the opportunity to create a document focused solely on assisting homeowners who rely on private water systems. The Pennsylvania Department of Environmental Protection, the Pennsylvania Ground Water Association, the Cooperative State Research, Education, and Extension Service Mid-Atlantic Water Program, and the National Ground Water Association have all demonstrated significant support of the Pennsylvania Master Well Owner Network (MWON). This publication would not be possible without their help. We would also like to acknowledge Susan Boser, James Clark, Tom McCarty, Gary Micsky, Dana Rizzo, Peter Wulfhorst, Melanie Barkley, Ann Wolf, Lisa Carper, and Marie Gildow for their assistance in compiling information used in this publication.

In addition, we thank the following reviewers:

Joseph Lee, Pennsylvania Department of Environmental Protection

G. Patrick Bowling, Pennsylvania Department of Environmental Protection

Thomas McCarty, Cumberland County Cooperative Extension

Todd Reichart, Pennsylvania Ground Water Association, and William Reichart Well Drilling

Mark Ralston, Converse Consultants, Inc.

Last, but certainly not least, we acknowledge the efforts of the MWON Volunteers. Without their contributions to the MWON program, much of the research and outreach related to this guidebook would not have been possible.

Contributing Authors

James Clark—Glossary

Stephanie Clemens—Spring Development and Protection, Testing Your Drinking Water, Tips for Buying Water Treatment Equipment, Coliform Bacteria, and Shock Chlorination of Wells and Springs.

Paul Robillard—Home Water Treatment in Perspective, Nitrates in Drinking Water, Corrosive Water Problems, Iron and Manganese in Private Water Systems, Hydrogen Sulfide in Pennsylvania Ground Water Wells, Removal of Arsenic from Wells in Pennsylvania, Reducing Radon in Drinking Water, Removing Giardia Cysts from Drinking Water, Water Softening, Magnetic Water Treatment Devices

William Sharpe—Protecting Wells with Sanitary Well Caps and Grouting, Spring Development and Protection, Rainwater Cisterns, Water Tests: What Do the Numbers Mean?, Home Water Treatment in Perspective, Coliform Bacteria, Nitrates in Drinking Water, Corrosive Water Problems, Lead in Drinking Water, Iron and Manganese in Private Water Systems, Hydrogen Sulfide in Pennsylvania Groundwater Wells, Removal of Arsenic from Wells in Pennsylvania, Reducing Radon in Drinking Water, Methane Gas and Its Removal from Wells in Pennsylvania, Removing Giardia Cysts from Drinking Water, Shock Chlorination of Wells and Springs, Water Softening, Magnetic Water Treatment Devices

Bryan Swistock—A Quick Guide to Groundwater in Pennsylvania, Protecting Wells with Sanitary Well Caps and Grouting, Spring Development and Protection, Water Tests; What Do the Numbers Mean?, Testing Your Drinking Water, Home Water Treatment in Perspective, Coliform Bacteria, Nitrates in Drinking Water, Corrosive Water Problems, Lead in Drinking Water, Iron and Manganese in Private Water Systems, Hydrogen Sulfide in Pennsylvania Groundwater Wells, Removal of Arsenic from Wells in Pennsylvania, Reducing Radon in Drinking Water, Methane Gas and Its Removal from Wells in Pennsylvania, Removing Giardia Cysts from Drinking Water, Shock Chlorination of Wells and Springs, Water Softening, Magnetic Water Treatment Devices, Roadside Dumps and Water Quality

Edward Young—Rainwater Cisterns

National Ground Water Association—Well-Decommissioning Procedures

James Garthe—Roadside Dumps and Water Quality

Albert Jarrett—Preventing On-Lot Sewage System Malfunctions, Septic Tank Pumping, On-Lot Sewage Systems

Contents

Introduction

Over three million rural residents of Pennsylvania rely on a private water system (individual well, spring, or cistern) for their home water supply. These water supplies generally provide adequate and safe drinking water for rural homes that lie outside the area served by public water supplies. In addition, surveys of homeowners with private water systems have found that more than 80 percent are satisfied with their water supply.

Despite this general satisfaction, rural homeowners often face challenges in managing their water supply. That's because, unlike public water supplies, managing private water systems is entirely the homeowner's responsibility. Some homeowners who grew up in rural areas are accustomed to private water systems, but the increased migration of city dwellers into rural areas has meant that many homeowners are unfamiliar with the basic management of these water supplies.

Homeowners may be unaware of the proper design, construction, testing, and treatment that are often necessary to ensure safe drinking water from these supplies. As a result, many problems go unnoticed. One recent study of 700 private well owners found that fewer than 20 percent were aware of the water-quality problems that existed in their drinking water.

This manual is intended as a guide for private water system owners in Pennsylvania. From proper location and construction to recommended testing and treatment strategies, it will help you make educated decisions about your water supply. Before following any of the suggestions made in this publication, check with your local, county, and state government to make certain that any existing regulations are met.

THE HYDROLOGIC CYCLE

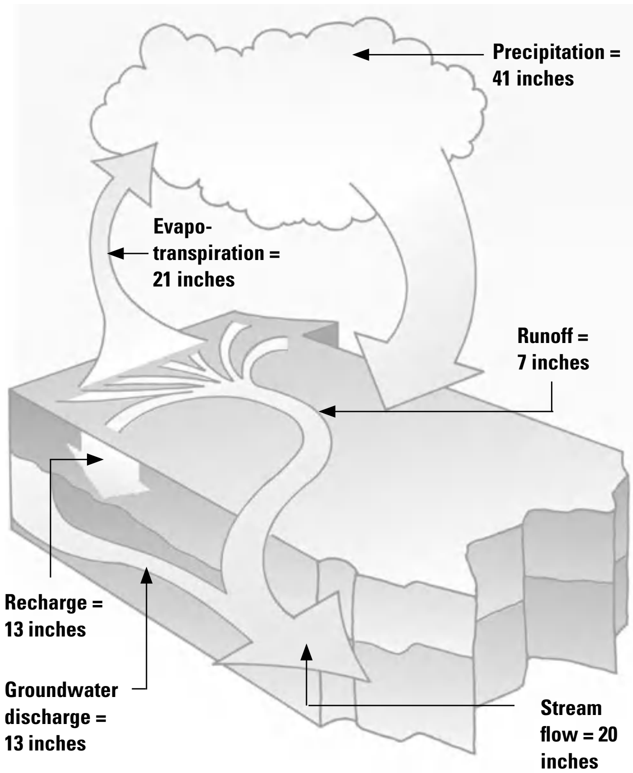
Any discussion of groundwater must start with an understanding of the hydrologic cycle, the movement of water in the environment. As the word “cycle” implies, there is no beginning or end to the hydrologic cycle; it is merely the continuous movement of water between places.

Let’s start with precipitation. Rain is the dominant form of precipitation across Pennsylvania, accounting for more than 75 percent of the total annual precipitation on average. Snow is the other major form, which generally accounts for less than 10 percent of the annual precipitation in southern Pennsylvania and up to 25 percent of the annual precipitation in some northern counties. The amount of precipitation is surprisingly variable across the state, ranging from just 32 inches in Tioga County to more than 48 inches along the Allegheny Front and the Poconos. On average, the state receives approximately 40 inches of annual precipitation (rain and melted snow) as a whole.

Where does all this precipitation come from? All precipitation originates from water evaporated somewhere on the Earth’s surface. Some of the rainfall in Pennsylvania comes from water that evaporated from tropical parts of the oceans. Near the equator, the sun provides enough energy throughout the year to evaporate huge quantities of water that fall as precipitation all over the world. However, precipitation during isolated thunderstorms or lake-effect snow squalls may originate from evaporation much closer to home.

The sun powers the hydrologic cycle, evaporating water from all over the Earth’s surface, including water in oceans, lakes, fields, lawns, rooftops, and driveways (Figure 1.1). Plants also use the sun’s energy to evaporate water by taking it from the soil, using it to grow, and releasing it into the atmosphere through their leaves in a process called transpiration. Evaporation and transpiration are commonly combined and referred to as evapotranspiration (ET). Nearly all the precipitation that falls during the growing season in Pennsylvania is returned to the atmosphere through ET. During the winter months, however, very little ET occurs because plants do not use much water and the sun is too low in the sky to cause much evaporation. Over the entire year, about 50 percent of the precipitation that falls across the Commonwealth returns to the atmosphere through ET.

Figure 1.1. The hydrologic cycle for an average year in Pennsylvania.



What happens to precipitation that reaches the earth and is not evaporated or transpired by plants? About 7 inches of Pennsylvania’s annual precipitation enters streams directly as runoff, either as overland flow, which travels over the land surface, or as interflow, which moves toward streams through soil. The remainder of the precipitation, about 13 inches, is in the form of recharge—precipitation that infiltrates the soil surface, trickles downward by gravity, and becomes the groundwater that feeds the springs, streams, and wells of Pennsylvania. Most of this recharge occurs from rain and melting snow during early spring and late fall when the soil is not frozen and plants are not actively growing. Adequate precipitation and snowmelt during these short time periods is critical for supplying groundwater. All groundwater was once surface water, and it will be again because groundwater is an integral part of the hydrologic cycle. This is nature’s way of recycling water.

GROUNDWATER BASICS

Precipitation that does not quickly run off into streams, is not evaporated by the sun, or does not get taken up by plant roots slowly infiltrates through layers of soil and rock to become groundwater. This infiltrating water eventually reaches a saturated layer of sand, gravel, or rock called an aquifer. Aquifers may occur a few feet below the land surface, but they are more commonly found at depths greater than 100 feet in Pennsylvania. Some groundwater occurs in the pore spaces of solid rock, but most occurs in cracks and fractures in rock layers or between sand and gravel particles. Therefore, groundwater normally occurs in small spaces within the different aquifer materials and not as underground lakes or rivers (Figure 1.2).

Geologic formations called aquitards may also lie within the saturated zone. These formations are usually made of clay or dense solid rock that inhibits infiltrating groundwater from moving through it. Aquitards restrict groundwater movement to and between aquifers. Aquitards located above and below an aquifer form a confined aquifer. If this aquifer is tapped with a well, artesian pressure forces the trapped water to rise in the well to an elevation higher than the top of the aquifer unit. If the pressure is great enough, the water may rise to the land surface, creating a flowing artesian well. An aquifer with no aquitard above it is an unconfined aquifer. In wells penetrating this type of aquifer, the water level within the well and the aquifer are the same. At any given location, several distinct aquifers may exist below the ground surface at different depths separated by aquitards.

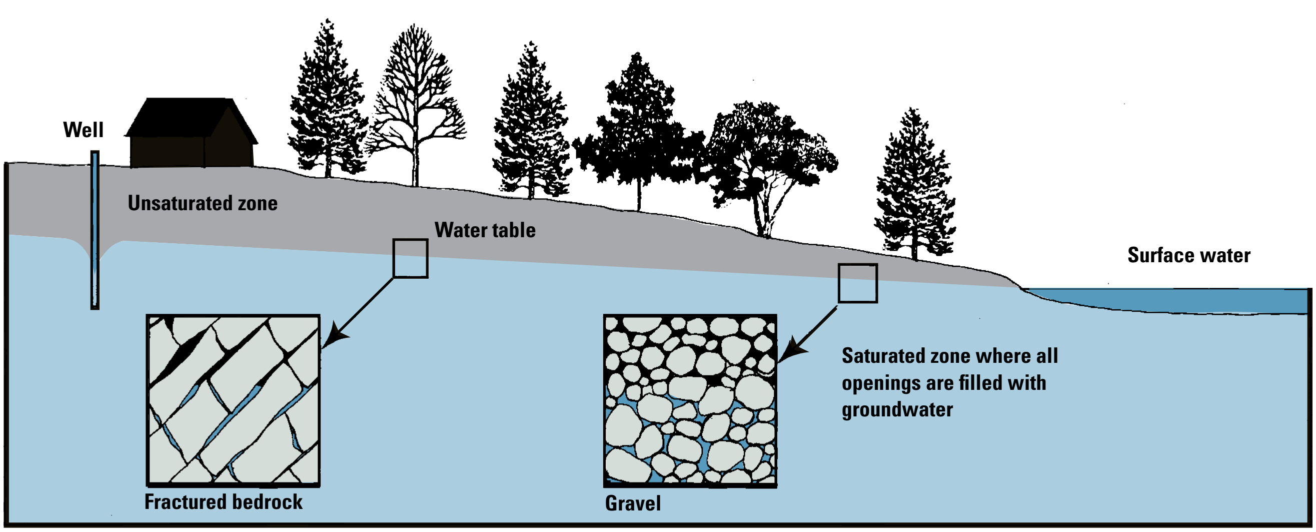
The top of the uppermost unconfined aquifer is called the water table. During rainfall, the water table rises toward the ground surface as percolating rainfall is added to the groundwater aquifer. During dry periods, the water table will fall deeper underground as groundwater is discharged from the aquifer into springs, streams, and wells.

Directly above the water table lies the unsaturated zone, where the spaces between soil and rock particles contain both air and water—air in the larger openings, water in the smaller ones. Moisture conditions in the unsaturated zone vary greatly depending on the weather. Immediately after a heavy rain, even the large pores of the unsaturated zone may hold water. During a drought, most pores are filled with air, and the little remaining water exists in thin films around soil particles.

Groundwater does not simply remain stagnant under the ground. Rather, it moves underground from upland to lowland areas. Groundwater flows downhill—the direction of groundwater flow underground can often be approximated by visualizing how water would flow on the ground surface. Flowing groundwater eventually reaches a discharge point where the water table meets the land surface. Springs are a classic discharge point where groundwater bubbling to the surface can be seen. Low-lying wetlands are another example of a discharge point where groundwater is at the soil surface.

Streams and lakes are the normal points of discharge for groundwater. Every stream has a watershed, which encompasses the land area that drains surface and groundwater into the stream. Very small streams

Figure 1.2. How groundwater occurs below the Earth's surface.



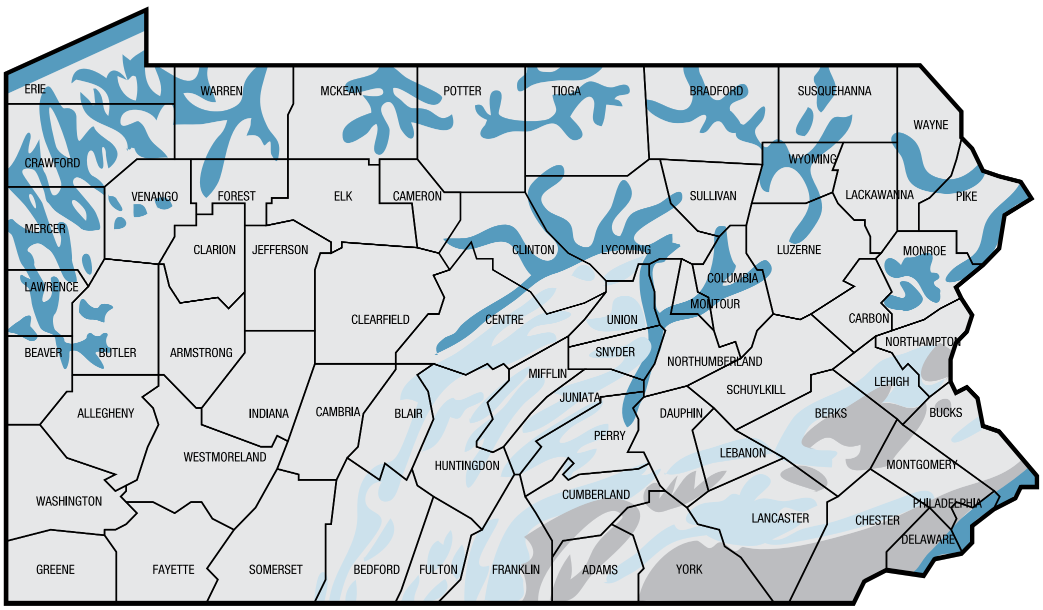
may have a watershed of only a few acres, while major rivers have watersheds that encompass millions of acres. No matter where you stand, you are located within one small watershed that is part of many other larger watersheds. The largest rivers forming the major watersheds of Pennsylvania all flow toward one of the oceans.

The average Pennsylvania stream gets about two-thirds of its flow from groundwater. Except for a short time during and after rainstorms and snowmelt, streams carry water provided only by groundwater that seeps through stream banks and streambeds into the channel (this is called baseflow). The groundwater that forms a stream's baseflow during dry weather often takes a year or more to make the journey underground to the streambed. In some groundwater flow paths, it may take thousands of years for an individual water molecule to travel to the stream after it reaches the land surface as precipitation.

The situation is sometimes reversed—streams may lose some of their flow to groundwater. This happens when the water table lies below a stream and does not intersect it. In some cases, different sections of streams behave differently, with some portions gaining groundwater and other losing it. In general, as streams become larger as they near the ocean, they contain increasing amounts of groundwater.

Groundwater aquifers vary in size and composition, and the amount and quality of groundwater yielded is also different from aquifer to aquifer. There are four major types of groundwater aquifers in Pennsylvania (Figure 1.3).

Figure 1.3. The four major types of groundwater aquifers in Pennsylvania.



Aquifer type and description		Depth (ft) Common range	Depth (ft) May exceed	Yield (gal/min) Common range	Yield (gal/min) May exceed	Typical water quality
Unconsolidated sand and gravel aquifers: sand, gravel, clay, and silt		20–200	250	100–1,000	2,300	Soft water with less than 200 mg/l dissolved solids; some high iron concentrations
Sandstone and shale aquifers: fractured sandstone and shale		80–200	400	5–60	600	Sandstone layers have soft water with less than 200 mg/l dissolved solids; shale layers have hard water and 200–250 mg/l dissolved solids
Carbonate rock aquifers: fractured limestone and dolomite		100–250	500	5–500	3,000	Very hard water with more than 250 mg/l dissolved solids
Crystalline rock aquifers: fractured schist and gneiss		75–150	—	5–25	220	Soft water containing less than 200 mg/l dissolved solids; some moderately hard water with high iron concentrations

Note: ft = feet; mg/l = milligrams per liter; gal/min = gallons per minute

From ***Pennsylvania Geological Survey***, 1999

An Important Resource

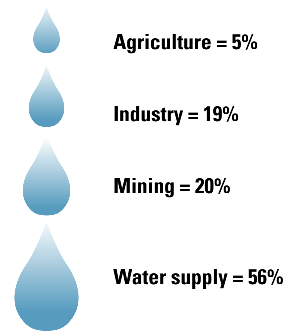
Groundwater in Pennsylvania is a vast resource and is estimated to be more than twice as abundant as the amount of water that flows annually in the state's streams. Pennsylvanians have tapped into this important resource. Each day more than one billion gallons of groundwater are pumped from aquifers throughout the state for various uses. More than half of this groundwater is used for domestic drinking-water supplies, which demand high-quality, uncontaminated water. Although smaller amounts of groundwater are used for agricultural and mining purposes, groundwater still accounts for the majority of all the water used for these activities (Figure 1.4).

Groundwater is especially vital to rural areas of the state. Second only to Michigan for the largest number of private water wells, Pennsylvania has more than one million private water wells, supplying water to more than three million rural residents (Figure 1.5). An additional 20,000 new private wells are drilled each year around the state.

Although more groundwater wells are drilled each year, the total groundwater usage across the state has remained relatively stable over the past few decades. Water conservation measures and education have played an important role in keeping groundwater use constant. From 1985 to 1995, Pennsylvania's population increased by nearly 300,000, but average water use fell from 66 to 62 gallons per person per day. Water conservation measures, such as low-flush toilets, front-loading washing machines, low-flow showerheads, and outdoor rain barrels, can reduce household water use by 30 percent. Reduced outdoor water use is especially important because it saves water that largely evaporates (consumptive water use) as opposed to water that is simply used and put back into the ground (nonconsumptive water use).

In addition to water savings, water conservation can also reduce yearly home energy costs by several hundred dollars in every home. Thus, conserving water means conserving energy. More information on water conservation can be found in Chapter 6.

Figure 1.4. Groundwater use in Pennsylvania.

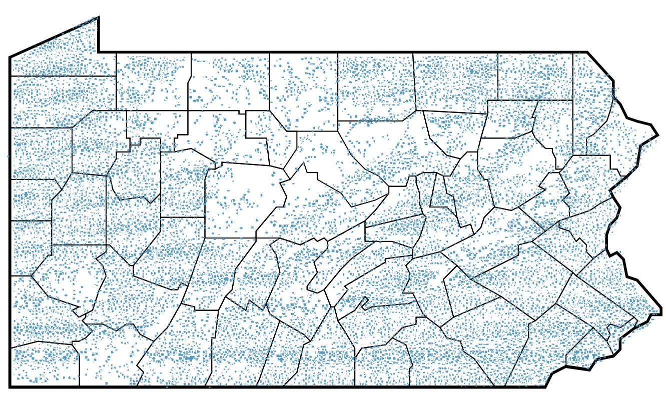


THREATS TO GROUNDWATER

People from many parts of Pennsylvania are concerned about the future availability of adequate groundwater for meeting home and business needs. In some cases, these concerns are due to increasing local use of groundwater that exceeds the amount of recharge supplying the aquifer. More often, groundwater supplies are threatened by expanding impervious coverage of the land surface. Each year, more land area is being covered by roofs, sidewalks, driveways, parking lots, and other surfaces that do not allow rainwater to recharge the underlying groundwater aquifers. Every acre of land that is covered with an impervious surface generates 27,000 gallons of surface runoff instead of groundwater recharge during a one-inch rainstorm. Without recharge water feeding the aquifer, groundwater mining—water being removed from the aquifer more quickly than it can be recharged—may occur.

Groundwater mining has been documented in parts of southeastern Pennsylvania, where impervious cover has increased rapidly and groundwater withdrawals have also increased. Water-resource planning efforts initiated in Pennsylvania in 2003 aim to document areas where groundwater resources are currently overused or may be overused in the future. With this information, local government planning officials can more adequately guide future development based on existing water resources.

Figure 1.5. Private water wells reportedly drilled between 1963 and 1994 to serve individual homes in Pennsylvania. Each dot represents one drilled well. *Data from the Pennsylvania Groundwater Information System compiled by the Pennsylvania Geological Survey.*



Over one million homes in Pennsylvania rely on a private water system. A private water system is any well, spring, or cistern that provides the drinking water supply for an individual household. Unlike public water systems, all the maintenance, testing, and treatment of a private water system is the homeowner's responsibility. For this reason, it is important for homeowners to understand private water systems and do periodic inspections and maintenance.

A private water well is a hole in the ground that is drilled, driven, or hand dug to supply water for an individual household. Most wells today are drilled by means of a cable tool (percussion) or by the air-rotary method. Hand-dug wells are usually very old but do still exist; they need to be closely monitored since they are very susceptible to pollution from surface sources and may also contribute to aquifer contamination. All private wells should be constructed using sanitary materials, such as a water-tight, vermin-proof well cap and a cement or bentonite grout seal between the borehole and the well casing.

A spring occurs where groundwater discharges to the earth's surface. If developed properly and treated for bacteria, springs can provide a safe and reliable source of water for an individual homeowner. Considerations such as the quantity of water that the spring produces throughout the entire year should be evaluated before the spring is used as the sole source of drinking water for the home.

Cisterns are the third type of private water system found in Pennsylvania. Although uncommon in most of the state, they are used in areas where the groundwater supply is grossly polluted and there is no alternative source for drinking water. A cistern is a tank, usually installed underground, that stores water for drinking and other household uses. Cisterns can store water that is trucked to the home or they can store treated rainwater. For a household to use rain as a source of drinking water, a roof catchment area needs to be installed and the appropriate treatment systems implemented. Water from rainwater cisterns must be disinfected before it can be used as a drinking water supply.

More information about each type of private water system can be found in this chapter. Regardless of which system is used in your home, it is important that the water supply be tested at least annually by a certified laboratory to ensure that the water is safe for consumption. In Pennsylvania, private water supplies are not monitored or regulated by the state, so homeowners need to evaluate their own systems periodically.

WATER SYSTEM PLANNING: ESTIMATING WATER NEEDS

Whether you are building a new house in a rural area or increasing the size of a dairy herd, an adequate supply of water from a private well or spring is critical to your plans. Planning should be done before you have a well drilled or spring developed to ensure that enough water is available.

This section allows a homeowner or farmer to estimate water needs and calculate how much water must be delivered from a private water supply to meet these needs. These planning assumptions are based on long-term averages for various water uses in Pennsylvania. Your actual water use may vary significantly from these averages.

Estimating Home Water-Use Needs

In general, we use 50 to 100 gallons per person per day in our homes (200 to 400 gallons per day for a family of four). The household water use estimates given in Table 2.1 can be used to calculate more specific daily water use values for your home.

For the purposes of planning a water system, the total daily water use is less important than the peak daily water use or the *peak demand*. In reality, most of

Table 2.1. Typical water uses for various appliances and fixtures in the home.

Clothes washer (top-loading)	43 to 51 gallons per load
Clothes washer (front-loading)	27 gallons per load
Dishwasher (standard)	7 to 14 gallons per load
Dishwasher (efficient)	4.5 gallons per load
Garbage disposal	4 gallons per day
Kitchen sink	3 gallons per minute of use
Bathroom sink	2 gallons per minute of use
Shower or tub	5 gallons per minute of use
Toilet (low-flush)	1.6 gallons per flush
Toilet (standard)	5 gallons per flush
Outside hose (1/2-inch)	5 gallons per minute of use
Water softener regeneration	50 to 100 gallons per cycle

the water used in the home occurs over very short time periods, usually in the morning and evening. As a result, for planning purposes it is recommended that a water system be able to supply all of the day's projected water use in a 2-hour peak demand period. If you estimate that your home water use will be 400 gallons per day, the water system should be sized to provide this much water in a 2-hour period.

The amount of water that can be delivered from your well or spring in a given period of time is referred to as the well or spring yield. The yield from a spring can be easily measured by determining how many gallons of water flow from the outlet pipe every minute. This flow rate will likely vary considerably with weather conditions, but, for planning purposes, it would be best to measure flow during a dry time period. For a well, the yield is considered the maximum rate in gallons per minute (gpm) that a well can be pumped without lowering the water level in the borehole below the pump intake.

For most single-family homes, a minimum flow of 6 gpm is suggested from a well or spring. This flow would provide 360 gallons of water each hour, which would be sufficient to meet most home water peak demands. Higher flow rates may be necessary for larger homes with more fixtures, appliances, and residents that may all be using water at the same time. The values in the table below give the suggested minimum flow rates for various numbers of bedrooms and bathrooms in a home.

Ideally, the yield from the well or spring will exceed the recommended minimum flow rates in Table 2.2. If not, you may need to rely on water storage to meet peak demand periods. For a drilled well, the borehole can provide a significant amount of water storage. A typical 6-inch-diameter well stores about 1.5 gallons of water for every foot of standing water in the borehole, and a 10-inch well stores about 4 gallons of water per foot. Therefore, a 6-inch-diameter well with about 100 feet of standing water in the borehole would contain about 150 gallons of stored water. However, in some geologic settings, using a significant amount of the borehole storage (i.e., significant drawdown for each pumping cycle) may tend to dislodge particles from the borehole and may result in the need to filter the water.

In the case of a spring, a large spring box can be constructed where the spring emerges, or a water storage tank can be added after the spring box to provide extra water storage to meet peak demand. The water stored in the borehole, spring box, or storage tank is helpful when water use in the home exceeds the amount of water flowing from the well or spring.

Well storage and spring flow can vary dramatically with the natural groundwater level, with the highest levels typically occurring in spring and the lowest levels in fall. These natural variations can be accentuated by drought conditions. So, while water storage can allow for the use of wells and springs with lower flow rates than shown in Table 2.2, it may not be reliable during severe droughts. An approximate estimate of the amount of water needed before a well or spring is developed can allow the professional contractor to use the combination of local knowledge, yield, and storage to meet water demand. For wells that yield extremely low amounts of water, an intermediate storage system can be added (see "Low-Yielding Wells" in Chapter 6).

Estimating Farm Water-Use Needs

Planning for water supply needs is generally much more important for farms because much larger amounts of water are often needed, especially for dairy operations or farms with large acreages in irrigation. Midwest Plan Service guidelines suggest that farms using 2,000 gallons per day (gpd) will need a water source flow rate of 16 gpm, those using 6,000 gpd will need 36 gpm, and those using 10,000 gpd will need 48 gpm. Planning for larger operations starts with an estimate of total daily water use from Table 2.3.

Using the estimates from Table 2.3, current and future daily water demands on the farm can be estimated. The farm water system would need to be designed to include sustained yield and storage from one or more wells or springs. Where large quantities of water are needed from a well, it may be worthwhile to hire a professional hydrogeologist to locate a high-yield well using fracture trace mapping or other technique for locating a productive well.

It should also be noted that farms using more than 10,000 gpd must report their annual water use to the Pennsylvania Department of Environmental Protection as required by the Water Resources Planning Act.

Table 2.2. Minimum flow rates (GPM) for homes based on number of bedrooms and bathrooms.

Number of bedrooms in home	Number of bathrooms in home			
	1	1.5	2	3
2	6 GPM	8 GPM	10 GPM	
3	8 GPM	10 GPM	12 GPM	
4	10 GPM	12 GPM	14 GPM	16 GPM
5		13 GPM	15 GPM	17 GPM
6			16 GPM	18 GPM

From *Private Water Systems Handbook*. 1002. Midwest Plan Service. MWPS-14.

Table 2.3. Estimated daily water use in gallons for various farm animals, equipment, processes, and irrigation in Pennsylvania.

Animal water use	
Milking cows	35 gallons per animal per day
Sprinkler cooling for animals	20
Dry cow, beef cattle, or steers	12
Calves	
1-month-old	1.5
2-month-old 2.0	2.0
3-month-old	2.5
4-month-old 3.5	3.5
5 to 14 months old	4.5
Heifers	
15 to 18 months old	7.0
18 to 24 months old	
Swine	1.5
Horses or ponies	12
Sheep or goats	2
Chickens (per 100)	9
Turkeys (per 100)	15
Milkhouse and parlor water use	
Automatic bulk tank	50 to 60 gallons per wash
Manual bulk tank	30 to 40 gallons per wash
Pipelines	70 to 120 gallons per wash
Pail milkers	30 to 40 gallons per wash
Milking system clean-in-place (parlor)	12 to 20 gallons per unit
Miscellaneous equipment	30 gallons per day
Cow preparation (per milking)	
Automatic	1 to 4.5 gallons per cow
Manual	0.25 to 0.5 gallons per cow
Wash pen	3 to 5 gallons per cow
Milkhouse floor	10 to 20 gallons per day
Parlor floor (hose down)	50 to 100 gallons per wash
Parlor floor and cow platform	500 to 1,000 gallons per wash
Parlor and holding area floor with flushing	
Parlor only	20 to 30 gallons per cow
Parlor and holding area	25 to 40 gallons per cow
Holding area only	10 to 20 gallons per cow
Automatic flushing	1,000 to 2,000 gallons per wash
Irrigation	
Sprinkler*	4,000 gallons per acre per day
Drip*	1,000 gallons per acre per day

*The amount of water used for irrigation is seasonal and varies greatly depending on natural water availability from precipitation.

The required water source flow rate does not necessarily need to equal the yield from the well or spring. If water availability is projected to be insufficient for the calculated peak water demand, additional sources must be developed or additional storage must be used (see "Low-Yielding Wells" in Chapter 6).

PROPER CONSTRUCTION AND MANAGEMENT OF PRIVATE WATER WELLS

Before You Drill a Well

When the decision is finally made to try using groundwater as a water supply for domestic use, livestock, and farmstead demands or irrigation, it is important that certain procedures be followed to ensure a clean, reliable, productive well. These important steps include siting, drilling, and pump testing the well. Although following the recommendations in this publication will not guarantee all the clean water you may need or desire to have, it will greatly increase your chances of having a clean, reliable, productive well that is able to meet your needs.

Finding a Qualified Driller

In most states, regulations were created to ensure that private water wells are constructed properly. In a few states, however, no private water well regulations exist. In this case, a well can be drilled using any materials, and the driller does not have to follow designated guidelines. In states without regulations, it is possible for well drillers to lack qualifications or training. Therefore, it is very important that you take the time to find a qualified well driller to make certain that the system is constructed properly. Find out if the driller is associated with any organizations such as a state association of well drillers or the National Ground Water Association. Usually well drillers with memberships in these organizations are more educated about proper well construction.

Also, talk to each well driller about the construction of your well. Tell the well drillers that you are interested in the process and see if they will take the time to explain what they are going to do. Find a qualified well driller at www.wellowner.org.

Before work starts, make sure to get a written contract that gives you a breakdown in cost and materials, provides liability insurance for the driller, and provides a guarantee of workmanship, etc.

The Proper Location

Groundwater exploration is not a hit or miss (or random) proposition. Excess rainwater percolates into the soil and rock beneath the earth's surface, accumulating in zones of saturation called aquifers. A well is a hole drilled into the aquifer from which a small portion of the groundwater can be pumped to the surface for use. It is true that any well penetrating an aquifer will yield water, but the amount of water produced from a randomly sited well may be very small.

Scientific methods have been developed for locating wells; such methods involve penetrating zones of fractured rock buried beneath the soil surface. Wells located on a fractured rock zone will produce much larger quantities of water than wells drilled into zones where the rock is not fractured. Finding the fractured rock zones, or better yet, finding the intersection of two fractured rock zones can be a time-consuming and expensive procedure. Only licensed geologists with training in aerial photo interpretation and hydrogeology are qualified to locate wells by the fracture-trace technique. If a high-producing well is desired, however, the consultant's fee for siting the well is money well spent.

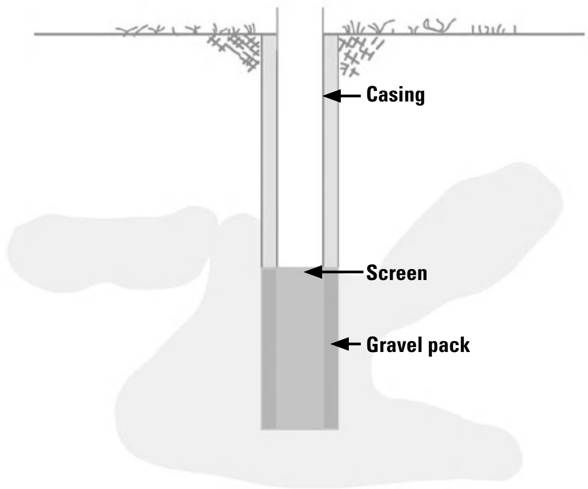
In addition to the siting considerations discussed above, which pertain to finding adequate water, wells should be located at least 50 feet from sewers and septic tanks; at least 100 feet from pastures, on-lot sewage system absorption fields, cesspools, and barnyards; and at least 25 feet from a silo. These distances are for residential wells and should be increased for farm wells in proportion to the demand placed on the well. Areas where groundwater comes to within 10 feet of the soil surface should also be avoided.

Drilling the Well

Drilling a well is more than boring a hole into the earth. A finished well consists of a borehole drilled into the aquifer at a diameter large enough to accept the well casing (see Figure 2.1), which receives the pump. The decision about how large the pump must be to meet your intended demand must, therefore, be made before drilling starts. The well casing is sized to meet the expected pumping need. For instance, a 6-inch casing will receive pumps that can pump up to approximately 100 gallons per minute (gpm). If you desire to pump more than 100 gpm you will need an 8-inch casing, which dictates at least a 12-inch borehole. Your well driller will actually make these decisions, but he must know your needs.

The borehole itself can be drilled using any one of several types of drill rigs, including impact, rotary, or various combinations. After the borehole has been drilled into or through the water-bearing aquifer, the well screen may be installed in the producing zone of the unconsolidated aquifer, or the well may be completed as an open borehole if it is drilled into a rock formation. The zones above the producing aquifer must be cased to prevent cave-ins, and the annulus (space) between the borehole and casing must be filled with grout to keep surface contaminants from entering the well. Read more about grouting later in this chapter.

Figure 2.1. Well components.



Developing the Well

Developing a well is the process of clearing the well of fine particles ("fines") left by the drilling operation, and flushing these fines out of the borehole and the first few feet of the aquifer. Development is accomplished by washing, air surging, bailing, or any operation that forces water through the development zone at high velocities. Developing a well is best done by the well driller right after the well is drilled. Properly developed wells may yield more water and will probably produce less turbidity (sediment) than poorly developed wells.

Pumping Test

With the well in place, the question remains, "How much water can be pumped from the well on a sustained basis?" The sustained pumping rate is dependent on the aquifer's ability to move water toward the well under the influence of gravity while the well is being pumped. To determine the sustained pumping capacity of a well, a "pumping test" should be performed on the well. The pumping test may be completed by the contractor as part of the well drilling contract. The desire for a pumping test must be made clear to the driller before drilling begins because some drillers are not able to do the pumping test.

Be sure to use a driller who can complete all drilling work, including the pump test.

Several types of pumping tests have been developed, but all are designed to establish the long-term equilibrium rate at which water will flow towards and enter the well. The simplest, most straightforward pumping test is to place a pump in the well, after the development phase is complete, and to pump water from the well at a constant rate. The pumped water must be discharged some distance from the well so it cannot recirculate back into the well during the pump test.

The pumping rate should be great enough to stress the well, but not so great as to cause the well to be pumped dry. During the pumping test, the water level in the well must be measured and recorded at regular intervals, starting at the time pumping begins and continuing until pumping stops. Pumping test durations for residential purposes are on the order of several hours; higher-yielding municipal and agricultural wells may have pumping tests that last for 24 to 72 hours or longer.

A cone of depression is produced when water is removed from the well bore by the pump, causing the water level in the well to drop. This means the water surrounding the well is at a higher elevation and the water in the rock begins to flow into the well bore. As this continues, the distance between the original water table and the water level in the well, or drawdown, increases and forms a cone of depression. At some point, the drawdown reaches a point of equilibrium, where the water flows to the well at the same rate as it is being pumped from the well, and the change in drawdown over time becomes very small or negligible.

The capacity of a well can be estimated by first determining the well's "specific capacity." Specific capacity (Sc) of a well is the pumping rate (Q) in gallons per minute (gpm) during the pumping test, divided by the drawdown (s) (in feet) at equilibrium. In other words, the specific capacity is the flow rate per foot of drawdown.

$$Sc = Q\ (\text{gpm}) \ /\ s\ (\text{ft})$$

Knowing the depth of the well and where the permanent pump will be placed, you can assume the maximum permissible depth to water in the well to be 10 feet above the permanent pump intake location. The difference in elevation between the original water table and the maximum permissible depth to water is the maximum drawdown, Smax. The maximum sustainable discharge for the well is then the specific capacity times the maximum drawdown.

$$Qmax = Sc\ (Smax)$$

Keep in mind that this method for estimating maximum sustainable discharge may overpredict sustainable discharge if the well is used continuously or for more than residential or light agricultural use. After the pumping test is completed, you will have gained knowledge about how much water the well can be expected to produce.

Sanitary Well Caps and Grouting

Pennsylvania is one of only a few states that do not have mandatory statewide construction standards for private water wells. (A few counties and townships have passed well construction ordinances—check with your local government office to determine if they are required in your area.) As a result, some important components of a properly constructed drinking water well are often not installed in an effort to reduce the cost of the well to the homeowner. The most important features missing from most private wells are a sanitary well cap and a grout seal. These components are required by most states because they help protect groundwater by sealing the well from potential surface contamination.

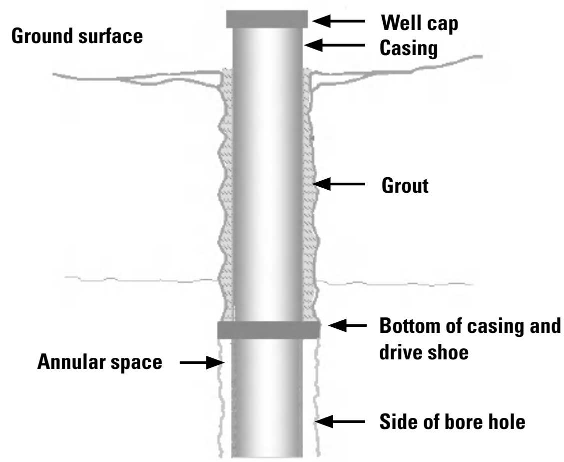
Types of Well Caps

Most existing and new wells in Pennsylvania have a standard well cap similar to the one shown in Figure 2.2. Standard well caps usually have bolts around the side that loosely hold the cap onto the top of the casing. Since these caps are nonsealing, the small airspace between the well cap and the casing can allow for insects, small mammals, or surface water to enter the well.

Figure 2.2. A standard well cap similar to those found on most Pennsylvania wells.

Figure 2.3. A sanitary well cap installed on a well casing.

Figure 2.4. Cross-section of a well casing showing the grout used to seal the annual space around the casing.



A "sanitary" well cap (sometimes referred to as a "vermin-proof" well cap) looks similar to a standard well cap but usually has bolts on the top of the well cap as shown in Figure 2.3. Most sanitary well caps include an airtight rubber gasket seal to prevent insects, small mammals, or surface water from entering the well and a small, screened vent to allow for air exchange.

What Is a Grout Seal?

Grout is usually neat cement (no aggregate) that is pumped into the space between the drilled hole and the casing—called the *annular space* (Figure 2.4). Bentonite, a clay material that expands when wet, is also often used for grouting a well. The grout is pumped into the annular space starting from the bottom of the casing using a tremie pipe. The grout is added until it appears at the surface of the ground. Since there are no residential well construction standards in Pennsylvania, grouting might not necessarily occur during the construction of a private well unless it is required by local ordinances, requested by the homeowner, or a part of the well contractor's standard operating procedure.

Can an Existing Well Be Grouted?

In general, it is not possible to grout an existing well. In rare cases, it may be possible to install a smaller diameter casing inside the old casing and grout between the casings. Another method used on existing wells is to pour a concrete slab around the existing well casing. However, these concrete slabs often crack and provide minimal protection from surface contamination. The best protection for an existing well is to make sure that the ground surface slopes away from the well casing in all directions to direct surface water away from the wellhead area.

Bacterial Contamination

Sanitary well caps and grout seal are installed primarily to prevent surface contamination, especially bacterial contamination. Bacterial contamination is a common problem that occurs in about 40 percent of the private water wells in Pennsylvania. Drinking water is typically tested for *total coliform bacteria,* which includes a large number of different species of bacteria, some of which can cause illnesses or diseases. For this reason, all drinking water supplies should be free of coliform bacteria. More information about coliform bacteria can be found in Chapter 4.

Bacterial contamination of groundwater wells can occur from both above and below the surface. Pollution of entire groundwater aquifers affecting many wells may occur from failing septic systems or animal wastes. Similarly, individual wells may be contaminated from the surface if contamination sources are located near the wellhead. Surface contamination of individual wells is usually caused by surface water or shallow soil water flowing down the outside of a well casing through the annular space; it can also be caused by a loose-fitting or absent well cap that allows insects, animals, or surface water to directly enter the well. Sanitary well caps and a grout seal can help prevent this type of contamination from occurring.

Does a Grout Seal and Sanitary Cap Prevent Contamination?

A 2002 study by the U.S. Geological Survey of more than 100 private wells in Pennsylvania examined the importance of grout in preventing bacterial contamination. This study found that ungrouted wells were three times more likely to be contaminated with *E. coli* bacteria compared to grouted wells. This same study, however, found that coliform bacteria were still quite common in grouted wells. Since the wells used in this study did not have sanitary well caps, the authors theorized that coliform bacteria were entering the well from the well cap area. This was supported by their visual assessment that found nearly 50 percent had obvious insect infestations under the well cap. Insects were found inside the well cap, on the wiring or plumbing, or inside the casing. Another study by the Wisconsin Department of Natural Resources found that insects could be a source of coliform bacteria in wells.

A recent Penn State study documented the effect of installing a sanitary well cap on existing water wells. Sixteen private wells containing coliform bacteria were disinfected with chlorine and fitted with a sanitary well cap. Of these wells, 44 percent did not contain coliform bacteria one month later and 19 percent did not contain bacteria after one year. The sanitary well caps were most successful in eliminating bacteria from wells that previously contained small numbers of coliform bacteria (less than 3 colonies per 100 mL of water), compared to those that had more gross contamination.

The study also looked at bacterial contamination in new wells that had been constructed with a sanitary well cap and a grout seal. Only 29 percent of these new wells contained coliform bacteria, suggesting that proper well construction practices can reduce but not completely eliminate bacterial contamination. Wells drilled into aquifers contaminated by animal wastes, septic systems, or surface water can contain coliform bacteria regardless of well construction practices.

What About the Cost?

Sanitary well caps and a grout seal are generally not used on private wells because of the added cost unless they are required by local ordinance. Sanitary well caps typically cost $40 to $50 compared to $20 to $30 for a standard well cap. A sanitary well cap can be installed by a homeowner with some basic knowledge of electrical wiring, or the cap can be installed by a well driller. In the recent Penn State study, the average cost for disinfection and installation of a sanitary well cap by a well driller was about $100 per well. Grouting of a new well typically adds $500 to $1,000 to the cost of the well. The cost of grouting will depend on the well depth, diameter, and type of bedrock in the area. It is the prerogative of educated consumers to therefore determine how best to spend their investment dollars—on proper well construction employing best practice methodology or on treatment equipment to address water-quality issues that may be related to substandard well construction.

What Can You Do?

Contamination related to an inadequate well cap or missing grout seal will most likely result in the presence of coliform bacteria in your well water. The first step in properly managing an existing private well, therefore, is to have an annual test done for total coliform bacteria. You can arrange this test through a local certified laboratory (a list of labs is available online at water.cas.psu.edu) or, in Pennsylvania, your regional Department of Environmental Protection office.

If your well tests positive for coliform bacteria, a sanitary well cap may help solve the problem, especially if your well contains small numbers of bacteria. Even if your well is currently free of bacteria, a sanitary well cap will help ensure that it does not become contaminated in the future by insects or other contaminants around the wellhead. Sanitary well caps can usually be purchased from a local water well contractor. Consult www.wellowner.org to find a local water well contractor certified by the National Ground Water Association. The contractor can also be hired to disinfect the well and install the sanitary well cap if you desire.

If you do the work yourself, the existing well cap should be removed and any obvious insects, nests, or small mammals should be removed from inside the well casing. Existing bacteria in the well water can be killed using a chlorine solution before installing the new well cap. (Note: installing the well cap should be done with caution owing to the involvement of electrical wiring.) Information about shock chlorinating your well can be found in Chapter 5. If you are having a new well drilled, you should request that the well be grouted to prevent surface contamination. If you have an existing grouted or ungrouted well, make sure the ground surface is sloped away from the casing in all directions to direct surface water away from the well.

Well Maintenance

After your well is properly constructed, it is very important to do preventative maintenance on an annual basis. Each year, a well owner should take the time to inspect the wellhead and the area surrounding it. This inspection should focus on finding cracks or damage to the well casing, checking the well cap to make sure it is in good condition and securely fastened, checking to make sure that water cannot pond around the wellhead, and looking for any nearby activities that could cause contamination to the water supply. You should also test your water each year at least for coliform bacteria. Include the annual water test report and notes from your annual inspection in a file that you keep with other important documents about your home.

Besides the annual preventative maintenance that a homeowner can perform, it is also beneficial to have a well inspection done by a qualified water well driller at least every ten years. Have these inspections more often if you harbor concerns about your well or the quality of your drinking water. A qualified well driller can be found at www.wellowner.org.

Dealing with Unused Wells

Pennsylvania has one of the largest rural populations of any state in the country, and most rural populations depend on private water systems for drinking water. Thus it is not uncommon to find old, unused wells throughout the state. Homeowners may choose to abandon a well on their property if it is plagued with problems and they believe that a new well will provide a high-quality water supply. A well may also go unused if it does not provide an adequate yield and a new well is thought to provide a more abundant water supply.

Regardless of the reason that a well is no longer in use, it is very important for any unused well to be properly sealed (or decommissioned) by a qualified well driller. The goal of sealing a well properly is to restore the area to the same condition (or better) that existed before the original well was drilled. An unused well that is not properly sealed becomes a direct conduit for surface contamination to affect the surrounding groundwater supply. In certain situations an unused well that is not sealed properly can lead to mixing between aquifers of poor and good water quality. Besides the potential pollution that an unused well might cause, it can also be a physical hazard and sealing it properly will help to prevent injury. *It is never acceptable for unused wells to be used for the disposal of any type of liquid or solid waste.*

Well-decommissioning Procedures

Many states have regulations detailing the procedures that should be used to properly seal an unused well. Pennsylvania currently has no statewide residential regulations regarding this process. The procedures outlined below are based on the recommendations of the National Ground Water Association. (Note: Pennsylvania has regulations and guidelines for properly decommissioning all public water supplies; guidelines for private water supplies can be found in the *Groundwater Monitoring Guidance Manual,* available from your local office of the Pennsylvania Department of Environmental Protection or on its Web site at www.dep.state.pa.us.)

The goal of sealing an abandoned well properly may vary depending on the well's construction, geological formations encountered, subsurface water chemistry, and prevailing hydrologic conditions. The basic concept governing proper sealing of abandoned wells is the restoration, as far as feasible, of the hydrogeologic conditions that existed before the borehole was drilled and the well constructed. This serves the purposes of removing the abandoned well as a conduit for loss of hydrologic pressure in confined formations, intermingling of groundwaters of differing quality, and entry of contaminated and polluted water.

The purpose of sealing an abandoned water well properly is to accomplish several objectives: (1) elimination of a physical hazard; (2) prevention of groundwater contamination; (3) conservation of yield and maintenance of hydrostatic head of aquifers; and (4) prevention of the intermingling of desirable and undesirable waters.

To seal an unusable or abandoned well or borehole properly, the hydrologic character of the groundwater encountered by the well must be considered. If the well was drilled into an unconfined aquifer (also referred to as a water table aquifer), the primary concern is to prevent surface water from entering the hole and contaminating the groundwater supply. If the unused well was drilled into a confined aquifer with artesian conditions, then the sealing procedure must be done so that water is restricted to its original aquifer and there is no loss of artesian head pressure. This will ensure that there is no contamination of surrounding aquifers or loss of artesian head pressure.

The first step in properly decommissioning a private water well is to hire a qualified professional. Use special consideration if the well to be plugged is a flowing artesian well. In this situation, you should select a driller who has extensive experience in sealing an artesian well. You can locate a well driller in your area at the Web site, www.wellowner.org. After a qualified driller is obtained, the following steps should be taken:

1. Research must be done on the well. Any records on the well, including the well log or maintenance records, should be found and given to the contractor. If no records can be obtained, then a down-hole camera and other techniques can be used to enable the contractor to gather information about the borehole.
2. It is strongly suggested that any material potentially hindering the proper sealing of a decommissioned well should be removed. In most situations, the well casing or liner should be removed from the borehole along with the pitless adapter, pump, screen, and any debris that has fallen into well. If the contractor finds that the casing cannot be removed, then it should be perforated or destroyed to the point that the pressurized grout fully comes into contact with the borehole walls

and properly seals the hole. If confirmed and documented evidence can be obtained that the annular space between the casing and borehole was indeed sealed and properly grouted during the well's installation and that these procedures were carried out in accordance with applicable state regulations and/or industry standards in absence of governing regulations, this segment of the operation can be bypassed with the agreement of all interested parties.

3. The well should be shock chlorinated (100 to 500 mg/L) to reduce the presence of bacteria and the chance that the sealed well might be a future source of bacteria for other wells in the area. In the event that chlorine concentrations greater than 100 mg/L are to be used, the contractor should consider the sealing material and methods to be used and the possible impact of elevated chlorine levels on the long-term sealing capacity of the sealing medium and method selected.
4. A grout or cement material chosen by the contractor should be used to seal the hole. The material will not plug the hole properly if it is dumped from the surface, since grout particles will separate as they fall through water. The sealing material must be introduced at the bottom of the borehole and filled up to the surface using a tremie or grout pipe, cement bucket, or dump bailer under pressure. Any borehole or well that is to be permanently sealed should be completely filled in such a manner that vertical movement of water within the well bore, including along the annular space surrounding the well casing, is effectively and permanently prevented. Methods and equipment used for the sealing should be selected based on recommendations from a qualified professional.
5. Information about the decommissioned well should be recorded and a copy of the report given to both the homeowner and the state or local regulatory agency.

More information about the National Ground Water Association and its specific recommendations for well decommissioning can be found at www.wellowner.org.

SPRING DEVELOPMENT AND PROTECTION

Springs occur wherever groundwater flows out from the earth's surface. Springs typically occur along hillsides, low-lying areas, or at the base of slopes. A spring is formed when the water table intersects the ground surface due to geologic or topographic factors. This can occur at a distinct point or over a large seepage area. Springs are sometimes used as water supplies and can be a reliable and relatively inexpensive source of drinking water if they are developed and maintained properly.

What to Consider

When considering using a spring as your source of drinking water, it is important to ensure that the rate of flow is reliable during all seasons of the year. Spring flow that fluctuates greatly throughout the year is an indication that the source is unreliable or may have the potential for contamination. It may be possible to learn about historical spring flow from the previous owner or a neighbor. Water quality is also important to consider before using a spring as a water supply. Before developing the spring, collect a sample of water and have it analyzed at a local water-testing laboratory to ensure that it can be efficiently and economically treated to make it safe for human consumption (see Chapter 4 for more information about water-testing options).

Springs may be susceptible to contamination since they are often fed by shallow groundwater, which may flow through the ground for only a short period of time and may interact with surface water. For this reason, most springs will need some treatment before the water is considered safe for drinking. Testing helps to determine exactly how much treatment is necessary and may help determine if other sources of water would be more economical.

Preparation

Since springs are often fed by shallow groundwater, water quantity may be an issue during certain times of the year. If possible, the flow rate for your spring should be monitored for an entire year, but it is most critical to measure the flow rate during late summer and fall when groundwater levels and spring flows are usually at their lowest. Springs used for drinking water supplies should yield at least two gallons per minute throughout the entire year unless water storage is going to be used. The amount of water you will need from your spring depends entirely on your household's daily water needs. Water needs for an individual home vary depending on water use, water storage, and water-saving devices within the home. However, the average home requires approximately 50 to 75 gallons of water a day per person. More information on determining your household water needs can be found at the beginning of this chapter.

The flow rate of a small spring can be tested by digging a five-gallon bucket into the outlet channel of the spring and allowing the water to flow into the bucket. Determine the flow rate in gallons per minute (gpm) by timing how long it takes the water to fill the bucket. Example below:

Flow rate = volume/time

$$= \frac{5 \text{ gallons}}{34 \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 8.9 \text{ gpm}$$

Obtain a sample collection container from a certified water lab and send a sample of the spring water to the lab for water-quality testing. A list of labs is available at water.cas.psu.edu/ or from your county Penn State Cooperative Extension office. You can start developing your spring once you determine that the quantity and quality are acceptable.

Procedures for Developing the Spring

A spring can be developed into a drinking water supply by collecting the discharged water using tile or pipe and running the water into some type of sanitary storage tank. Protecting the spring from surface contamination is essential during all phases of spring development. Springs can be developed in two different ways; the method you choose will depend on whether it is a concentrated spring or a seepage spring. The general procedures for spring development are outlined in the following pages. Some of these procedures are adapted from the Midwest Planning Service publication, *Private Water Systems Handbook*. This publication (MWPS-14) is available for purchase at www.nraes.org or by calling NRAES at 607-255-7654.

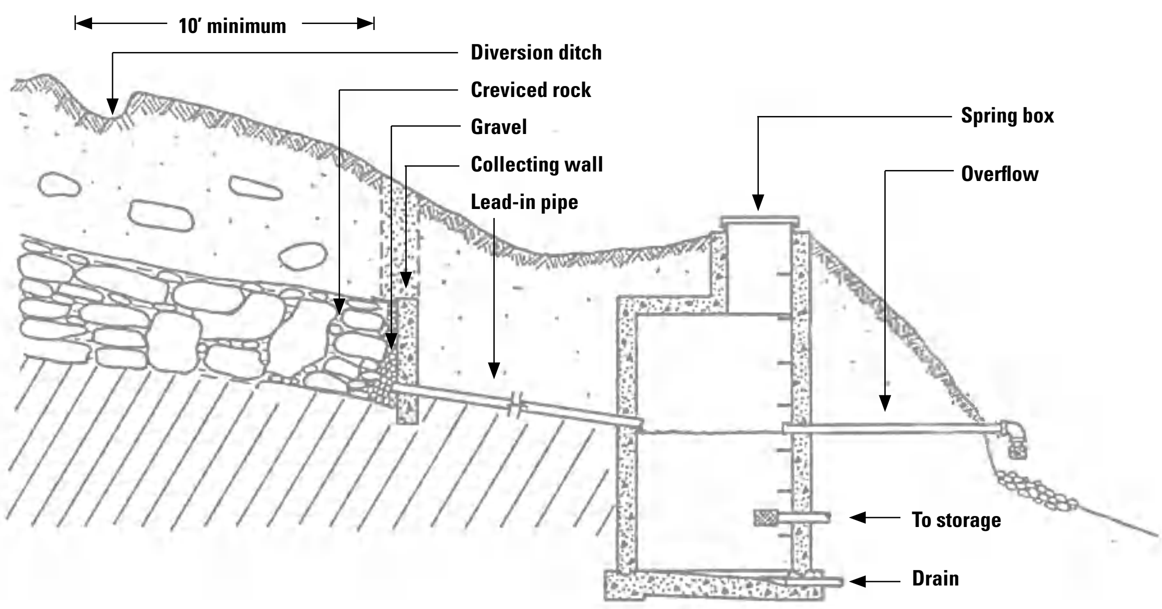
Concentrated Springs

A concentrated spring typically occurs when groundwater emerges from one defined discharge in the earth's surface. Concentrated springs are visible and are often found along hillsides where groundwater is forced through openings in fractured bedrock. This type of spring is relatively easy to develop (see Figure 2.5) and is usually less contaminated than other types of springs.

Steps for developing a concentrated spring are as follows:

- Excavate the land upslope from the spring discharge until water is flowing three feet below the ground surface.
- Install a rock bed to form an interception reservoir.
- Build a collecting wall of concrete or plastic downslope from the spring discharge.
- Install a pipe low in the collecting wall to direct the water from the interception reservoir to a concrete or plastic spring box. (Note: problems with spring flow can occur if water is permitted to back up behind the wall.)
- Remove potential sources of contamination, and divert surface water away from the spring box or collection area.
- Alternative types of interception reservoirs and collecting walls can be constructed.

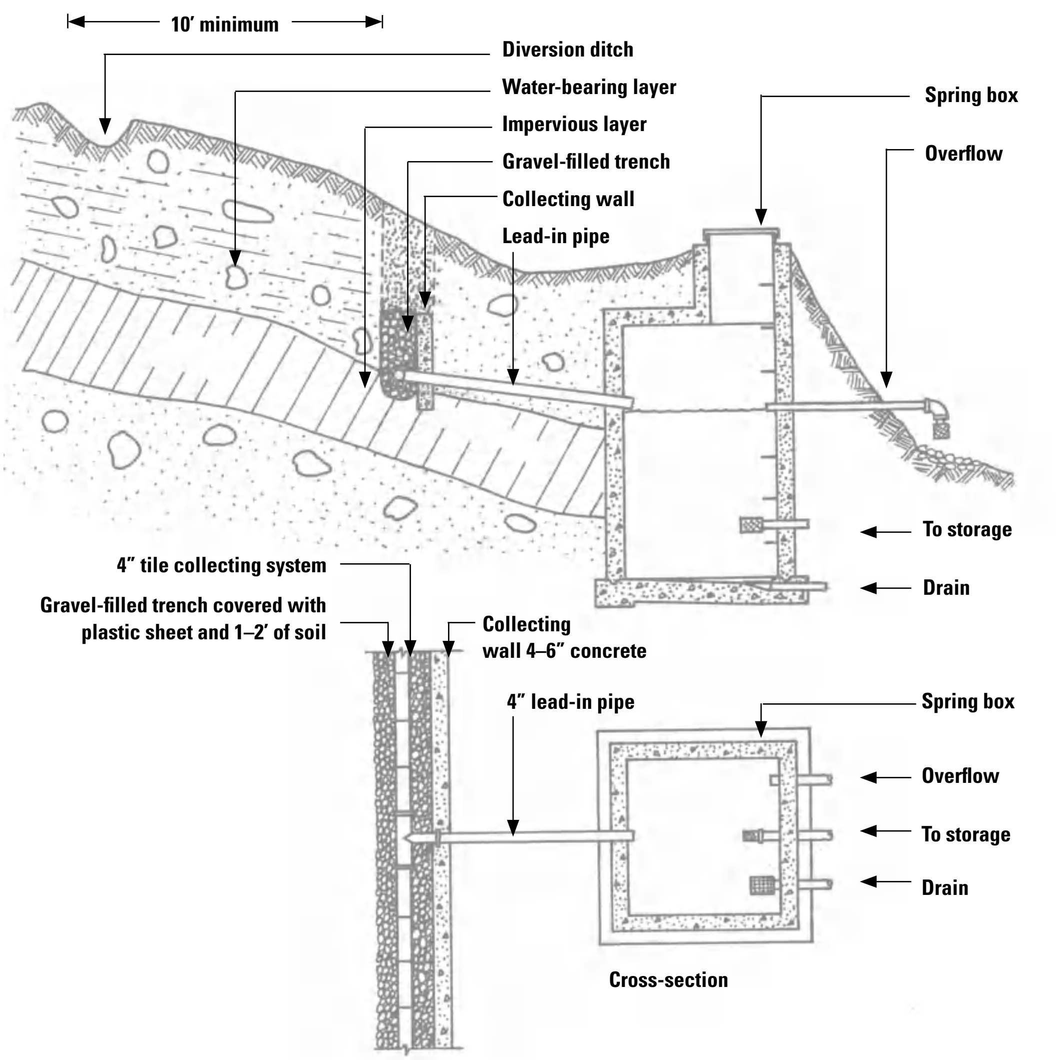
Figure 2.5. Development of a typical concentrated spring.



Seepage Springs

Seepage springs occur when shallow groundwater oozes or "seeps" from the ground over a large area and has no defined discharge point. This type of spring usually occurs when a layer of impervious soil redirects groundwater to the surface. Seepage springs can be difficult to develop (see Figure 2.6). They are also highly susceptible to contamination from surface sources, and they need to be monitored before development to ensure that they will provide a dependable source of water during the entire year. Flow is often lower from seepage springs, making them less dependable.

Figure 2.6. Spring development in a seep area.



Note: Trench should be 18–24″ (inches) wide, extend 6″ (inches) into (but not through) the impervious layer, and reach 4–6′ (feet) beyond the seep area on each side.

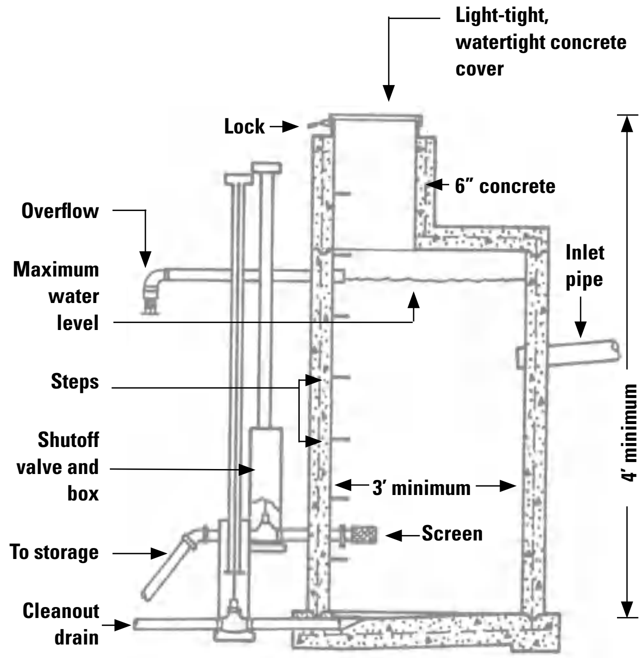
Spring Box Considerations

A spring box is a water-tight structure built around your spring to isolate it from contaminated surface runoff. (See Figure 2.7.) It is critical that this box be built properly to ensure that surface water, insects, or small animals cannot enter the structure. If designed properly, it can provide a small amount of reserve storage during a situation when the spring flow rate is below normal. It is important to keep surface water away from the spring box, and animals should be fenced out of the spring's drainage area. All activities should be kept to at least 100 feet from the spring box.

- Dig test holes upslope from the seep until you locate the point where the impervious layer is 3 feet underground.
- Create a trench approximately 18 to 24 inches wide across the slope. The trench should be extended 6 inches into the impervious layer (below the water-bearing layer) and should extend 4 to 6 feet beyond the seepage area. Install 4 inches of perforated pipe and surround it with gravel.
- Installing a collecting wall will help prevent water from escaping the collection tile. This collecting wall should be constructed of 4 to 6 inches of concrete.
- Perforated pipe or collection tile should be connected to 4-inch pipe that leads to the spring box. The box inlet must be below the elevation of the collector tile.
- Remove potential sources of contamination and divert surface water away from the spring box and collection area (Figure 2.8).

Figure 2.7. Spring box example.

Figure 2.8. Spring box construction.



Proper Management of Springs

No matter what type of spring you have developed, it is critical that you remove potential sources of contamination from the spring's drainage area (the area upslope of the spring discharge point). Make sure to keep water-quality-threatening activities to at least 100 feet from a spring box, especially in the upslope position. Surface water draining into that area should be redirected and all activities limited within the drainage area. If livestock are present, use fencing to keep animals out of the drainage area.

Once the spring is developed and nearby sources of contamination are eliminated, it is important to disinfect the entire water system and then submit a water sample to a state-certified water-testing laboratory for water-quality analysis. If a water test indicates bacterial contamination, check the water supply location and construction of the system for potential pollution pathways. If improvements can be made, the system should then be shock chlorinated. After two weeks, have the water retested by a state-certified water-testing laboratory. If the water again tests positive for bacterial contamination, you have the option of finding a new source of water or installing a continuous disinfection system, such as an ultraviolet light. Most springs used for drinking water require some type of continuous disinfection system to make certain that the water is safe for consumption. For more information on treating water supplies containing coliform bacteria, consult Chapter 5.

Drinking Water from Roadside Springs

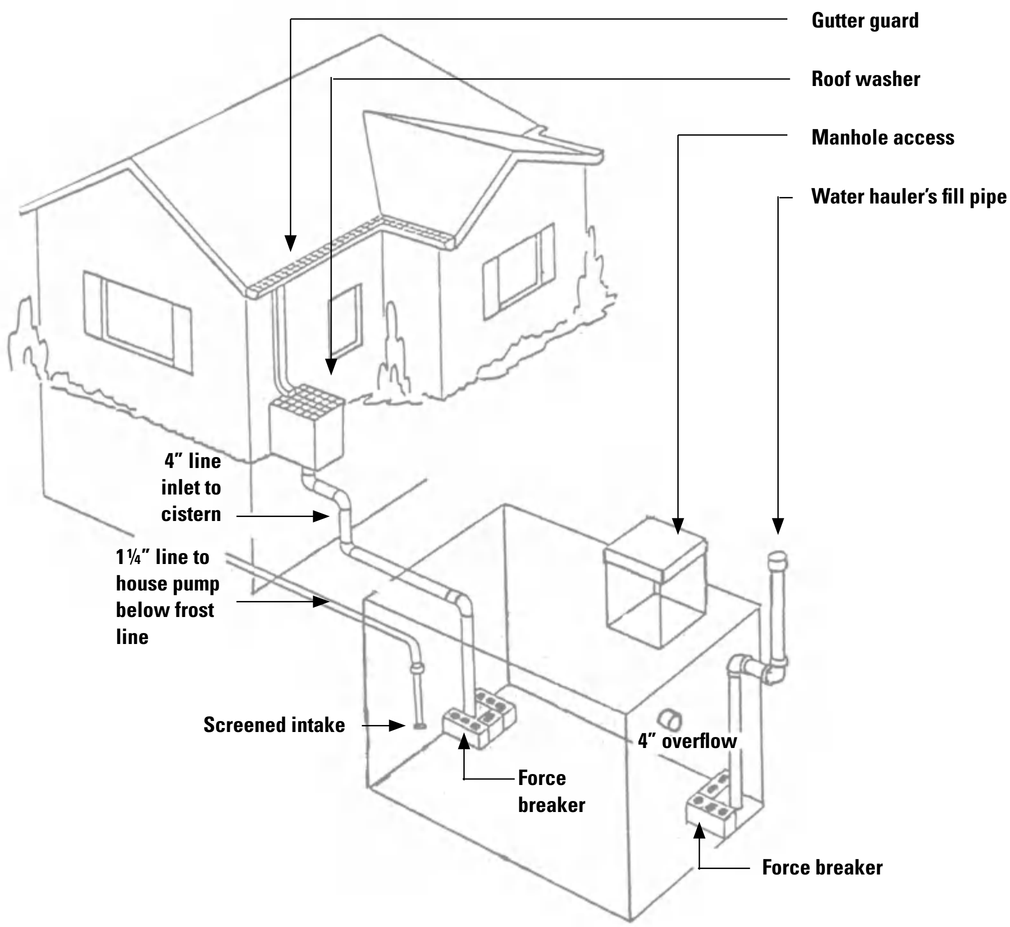
In Pennsylvania it is not uncommon for rural residents to use roadside springs for drinking water. It's important to understand, however, that roadside springs are just as vulnerable to bacterial contamination as other privately owned springs. In fact, many roadside springs that are located on public property may already undergo disinfection to ensure that the source is safe for consumption. Any roadside spring that is being used as a drinking water supply should be tested for total coliform bacteria. These springs should only be used as a source of drinking water if they have been tested and found to be bacteria free. When it comes to your family's health and safety, never assume that a water supply is safe for drinking. Surveys conducted by Penn State researchers have found that more than 75 percent of untreated springs contain unsafe levels of bacteria.

RAINWATER CISTERNS

Roof-catchment cisterns are systems used to collect and store rainwater for household and other uses. Such systems consist basically of a house roof, or catchment, and a storage tank or cistern. A system of gutters and downspouts directs the rainwater collected by the roof to the storage cistern. The cistern, typically located underground, may be constructed of various materials including cinderblock, reinforced concrete, or precast concrete, fiberglass, or steel. The cistern supplies water to the household through a standard pressurized plumbing system. A typical arrangement for a roof-catchment system is shown in Figure 2.9.

Current use of rainwater cisterns may be increasing. Those who live in areas where groundwater and surface water are unobtainable or unsuitable for use have been compelled to resort to cisterns as sources of water. Rainwater collection on a household scale is quite practical in areas where there is adequate rainfall and other acceptable sources of water are lacking. The coal strip-mining region of western Pennsylvania is one such area. Mining has rendered much of the

Figure 2.9. Typical roof-catchment cistern system.



ground and surface water unfit for drinking and other uses in large portions of these areas. Rural residents, forced to find other sources of water, have invariably turned to roof-catchment cisterns.

Roof-catchment cisterns may also be used to supply water to farms. Watering troughs and rain barrels can be filled by water collected from barn and other outbuilding roofs. A storage cistern built alongside a barn or other building could serve as an emergency source of water for firefighting in the event that a pond was not nearby. However, the use of rainwater for supplying domestic water needs is not without its problems.

Water-quality is of concern, especially when the rainwater is to be used for drinking in addition to other domestic uses. Rainwater and atmospheric dust collected by roof catchments contain certain contaminants that may pose a health threat to those consuming the water. Lead and other pollutants may accumulate in cistern bottom sediments; and untreated rainwater is quite corrosive to plumbing systems. Measures must be taken to minimize these and other water-quality problems in cistern systems. Recommendations for doing this are presented below, as well as guidelines for designing and building roof-catchment cistern systems.

Cistern Design

The storage capacity of a rainwater cistern depends on several factors:

- the amount of rainfall available for use
- the roof-catchment area available for collecting that rainfall
- the daily water requirements of the household
- available money supply

All but the first of these factors can be controlled to some extent by the cistern owner.

Available Rainfall

Across most of Pennsylvania, annual rainfall averages around 40 inches. During drought years there may be as little as 30 inches, while excessively wet years may produce 50 or more inches of rainfall. For most planning purposes the average figure should be used, although designing a cistern based on the lowest figure would guarantee enough storage to get you through even the driest years.

Owing to evaporative and roof-washer losses (to be discussed later), only about two-thirds of the annual total rainfall is actually available for cistern storage.

Daily Water Needs

The amount of water you design your roof-catchment cistern to collect and store depends on your daily water needs. If you have a small catchment area and a low-volume cistern, then your water use will be limited accordingly. So it is important when designing a roof-catchment cistern system to have some idea how much water you will require from it every day.

Various estimates of household water use have been published. The average base use determined by water utilities is 7,500 gallons per month, which is equivalent to an average yearly minimum need of 90,000 gallons per household. Common household planning provides for 50 to 75 gallons a day per person, or 73,000 to 110,000 gallons a year for a family of four. One-third to one-half of this amount is used for flushing toilets. However, those who must rely solely on rainwater-fed supplies will undoubtedly use less water.

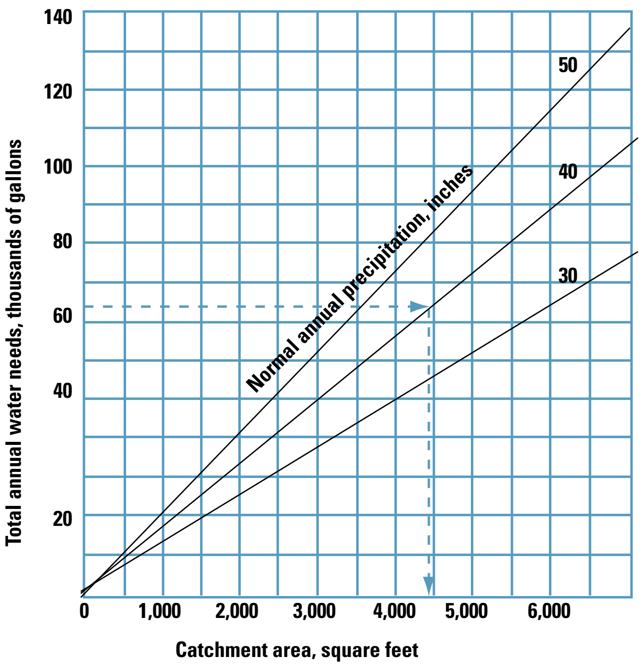
It should be clear from this brief discussion of water use that there is considerable variation, depending on the circumstances. For purposes of general cistern design, the figure 50 gallons a day per person is probably the best one to use. This figure would be applicable for a family living in a home with hot and cold running water and all the modern conveniences (including automatic washer and dishwasher), and no special water conservation measures. The installation of water-saving devices could considerably reduce household water use with no conscious effort on the part of family members. Additional information on water conservation in the home can be found in Chapter 6.

Catchment Area

The roof area to be used as the collection surface is usually predetermined by the size of the existing house or other outbuilding roofs. However, when planning a rainwater collection system from the ground up, where the size of the catchment is to be designed to suit domestic water needs, the following guidelines will be useful.

Figure 2.10 allows the catchment area required to be determined based on annual water needs and annual precipitation. As an example, suppose the average annual precipitation for your area is 40 inches. You have determined that your family of four requires 200 gallons a day or 73,000 gallons annually. From Figure 2.10 the needed catchment area is determined to be 4,400 square feet. (Note: Roof area can be determined by measuring the outside of the building or buildings to be used to collect rainfall. Do not measure the actual roof surface unless it is horizontal.)

Figure 2.10. Graph used to determine catchment area needed.



Cistern Size

A cistern should have sufficient storage capacity to carry the household through extended periods of low rainfall. A three-month supply of water, or one-fourth of the annual yield of the catchment area, is generally adequate in areas such as Pennsylvania where the rainfall is distributed fairly evenly over the course of the year. For example, if you have determined your annual domestic water needs to be 40,000 gallons (and most important, you have enough catchment area and annual precipitation to supply this amount of water), then you should design and build a cistern with a 10,000-gallon storage capacity.

A minimum storage capacity of 5,000 gallons is recommended for domestic cisterns. This capacity should eliminate having to buy or haul water, a practice that is not only inconvenient but can become somewhat costly. Remember these words of wisdom when designing your roof-catchment cistern: "You pay for a large cistern once and a small one forever."

Cistern Construction

Location

Cisterns should be located as close as possible to the house or wherever the water is to be used. They may be built above or below ground, but below-ground cisterns are recommended in this part of the country to avoid freezing during the winter months. Underground cisterns also have the advantage of providing relatively cool water even during the warmest months of the year. Cisterns may be incorporated into building structures, such as in basements or under porches. This way you can use foundation walls for structural support as well as for containment of stored rainwater.

A cistern should be located where the surrounding area can be graded to provide good drainage of surface water away from the cistern. Avoid placing cisterns in low areas subject to flooding. Both of the above steps will reduce the chance of storm runoff contaminating the stored cistern water.

Cisterns should always be located upslope from any sewage disposal facilities; at least 10 feet away from watertight sewer lines and drains, at least 50 feet away from non-watertight sewer lines and drains, septic tanks, sewage absorption fields, vault privies, and animal stables, and at least 100 feet away from sewage cesspools and leaching privies. It pays to check these things out carefully before turning the first shovelful of earth for the cistern excavation.

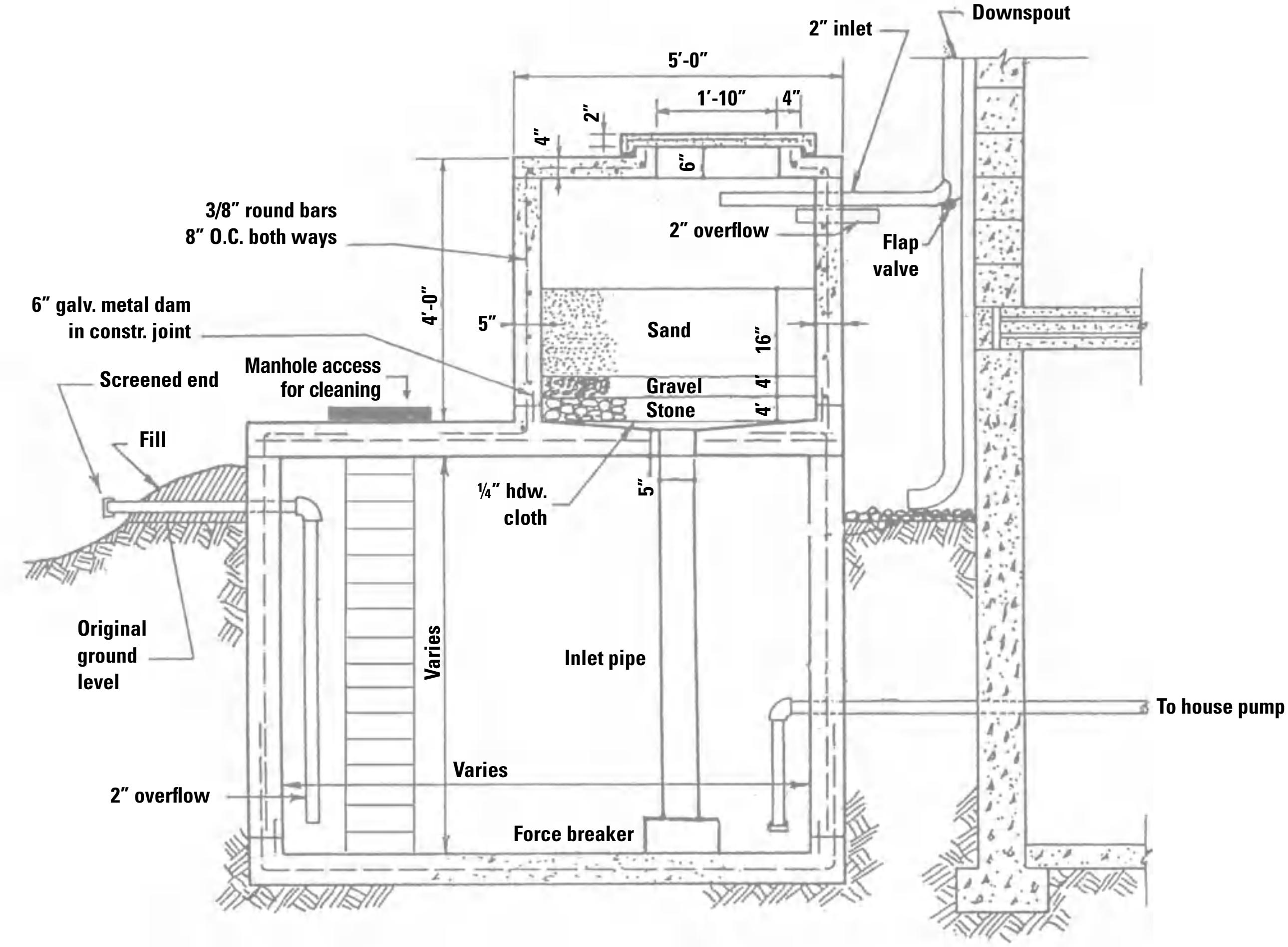
In certain situations, such as a barn or other outbuilding roof that supplies collected rainwater to a house downslope, cisterns may be located so as to provide gravity flow to the place of use. This setup is definitely preferable if it can be worked into your particular system. In most cases, however, the level of water stored in underground cisterns is lower than the points of use within the distribution system, so a pump and pressurized system are usually required.

Construction

Cisterns can be constructed from a variety of materials, including cast-in-place reinforced concrete, cinderblock and concrete, brick or stone set with mortar and plastered with cement on the inside, ready-made steel tanks, precast concrete tanks, redwood tanks, and fiberglass. Cast-in-place reinforced concrete is considered the best, especially for underground cisterns. However, cinderblock-walled cisterns with concrete floors are common and quite satisfactory for below-ground construction; these are usually somewhat less expensive than the all-concrete version. Concrete walls and floors should be at least 6 inches thick and reinforced with steel rods.

A general plan for a below-ground concrete cistern is shown in Figure 2.11. If cinderblock or concrete block is used for the walls of the cistern, all hollow cores should be filled with concrete and reinforced rods should be placed vertically to add strength to the structure. Footers may be necessary for larger cisterns. Footing drains should be installed around the perimeter of the cistern and drained to daylight. This reduces the chances of contaminating cistern water from the outside and also prevents the possibility of saturated soil providing an excessive horizontal load against the cistern walls.

Figure 2.11. Cross-section of a concrete cistern with filter (not to scale).



The top of the cistern should be reinforced concrete and should fit tightly onto the rest of the structure. The top may consist of individual panels or it may be a one-piece slab. In any event, a manhole through the top of the cistern to allow access to the storage tank should be included. Such an opening should be at least 2 feet across. A heavy concrete or iron lid should be fitted tightly over the opening to prevent the entrance of light, dust, surface water, insects, and animals.

Manhole openings should have a watertight curb with edges projecting several inches above the level of the surrounding surface. The edges of the manhole cover should overlap the curb and project downward a minimum of 2 inches. Manhole covers should be provided with locks to further reduce danger of contamination and accidents.

Place the manhole opening near a corner or an edge of the structure so that a ladder can be lowered into the cistern and braced securely against a wall. The access is necessary for the periodic maintenance tasks, to be discussed later. An alternative is to build concrete steps and handholds into the cistern wall beneath the opening.

The interior walls and floor of the cistern should be smooth to make cleaning easier. A cement plaster can be spread over the interior, depending on how rough the basic construction is. Cement-based sealants, such as Thoroseal and Sure-Wall, can be applied to the interior as well, to provide a smoother finish and further protection against leakage. A cistern that leaks is useless, but it is dangerous as well; if stored water can leak out, contaminated surface and groundwater can leak in. It is worth the time when building a cistern to do it right—get a good builder who will guarantee his work against leakage.

Vinyl liners may be used to prevent leakage in some cisterns, but they are usually troublesome. They are expensive and prone to puncture, and they prevent the use of cleanout drains and other accessories inside the cistern. Try a vinyl liner only as a last resort when all other efforts to prevent leakage have failed.

Another important feature of a well-designed cistern is an overflow pipe or pipes. The overflow can be in the form of a standpipe that leads through the floor of the cistern to a drain. Such an overflow pipe, or any other cistern outlet for that matter, should never be connected to a sewer line, either directly or indirectly. The drain line can also lead to a free outlet downslope from the cistern. The diameter of the overflow pipe should be at least as large as the diameter of the inflow pipe from the roof catchment.

The outside end of an overflow pipe should be effectively screened using a fine mesh rust-proof screening to prevent the entrance of animals and insects. The screening can be cut to a size large enough to be wrapped over the end of the overflow pipe and should be secured with a hose clamp or similar fastening device.

Large-diameter plastic pipe should be used for the overflow pipe in any case. When designing overflow outlets, it's important to provide good drainage away from the cistern and house.

A cleanout drain is also a key feature that allows the cistern to be drained for periodic cleaning and maintenance. A cistern without a drain has to be pumped out before any maintenance or cleaning can be done.

A cleanout drain should lead to a free outlet and never a sewer line. The floor of the cistern should be sloped slightly toward the drain for ease of cleaning. A valve to open and close the drain should be controlled from above ground level. The valve and drain line should be insulated by a sufficient depth of earth to prevent freezing during even the most severe winter weather.

The cleanout drain line needs to be at least 3 or 4 inches in diameter to avoid clogging—a large amount of sediment may have to move through the line during cleaning operations. The outlet should be located where draining water will not cause any problems or complaints from neighbors.

Cisterns should be vented to allow fresh air to circulate into the storage compartment. One or more large diameter pipes through the top of the cistern will serve this purpose. The outside opening of each pipe should be screened in the same manner as that described above for overflow pipes. The openings, located several feet above the ground level, should face the direction of the prevailing winds, west in most cases, to maximize ventilation. Four or six-inch diameter plastic pipe is good for vents. Make sure there is a watertight seal where each vent pipe goes through the top of the cistern.

The water line from the cistern to the house or other place of use should be buried below the frost line and should be 1 or 1¼ inches in diameter. The intake head should be effectively screened and elevated a minimum of one foot above the floor of the cistern to prevent sediment from being drawn into the distribution system. The portion of the intake pipe within the cistern should be plastic. The best position for the intake is on the opposite side of the cistern from the roof-water input pipe.

A separate input pipe for adding hauled water is another important feature of the well-designed cistern. Where possible, it is best to locate the above-ground portion of the fill pipe near the driveway or other road surface, so that the water truck does not have to drive over your lawn to reach it. Four-inch plastic pipe makes a good fill pipe. Place a tight-fitting cap over the above-ground end of the pipe. You may want to padlock the cap to further reduce the possibility of contamination.

Water entering the cistern with any kind of force behind it, as during a summer thundershower, or from a water truck, tends to agitate the stored water and possibly stir up sediment unless steps are taken to lower the force of the incoming water. One way of doing this is through the use of "force breakers."

Water entering the cistern from either the roof or a water truck should travel down a 4-inch plastic pipe into a force breaker box made from concrete blocks. The blocks should be set in mortar on the floor of the cistern with the cavities facing up. Slots or openings with an area of at least 13 square inches need to be cut into the lower end of the pipe to allow the incoming water to move from the pipe to the cistern. Force breakers should be installed under both roof-water and water-hauler inlets.

Roof Washers

Several other very important construction features will help ensure good-quality cistern water. Roof washers and roof-water filters were mentioned earlier, and their importance and construction details are discussed here.

A lot of dirt and dust collects on the roof-catchment surface between rainstorms. This debris can include particles of lead and other atmospheric pollutants as well as bird droppings. These contaminants will enter the cistern along with the roof water unless steps are taken to prevent contamination. The use of roof washers and roof-water filters can reduce the amounts of these contaminants entering the system.

The first water to come off the roof at the beginning of the rainstorm is the most contaminated. The degree of contamination will depend on several things including the length of time since the last rainfall, proximity of the catchment to a highway or other local source of airborne pollution, and the local bird population. Also, certain types of materials are preferable for the catchment surface, as will be detailed later.

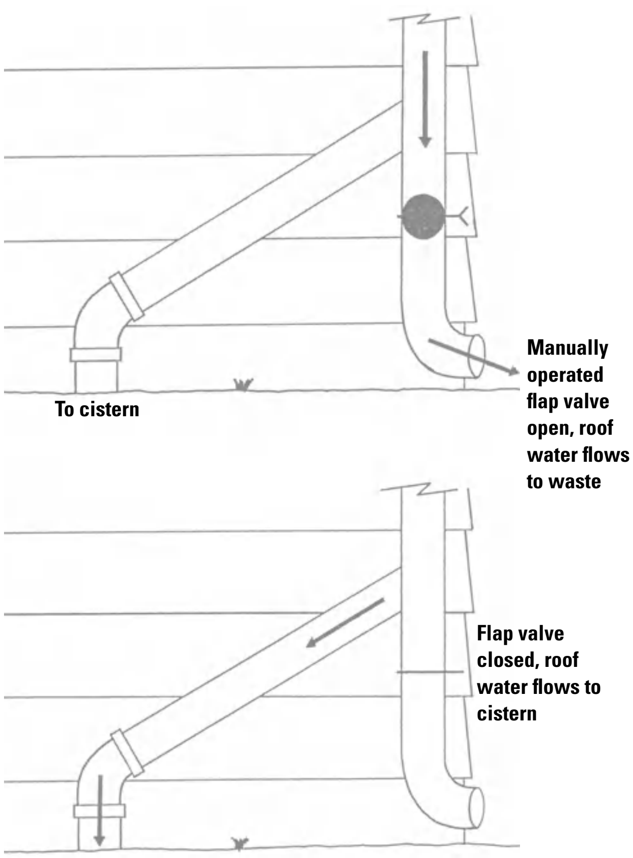
A roof washer is a mechanism that diverts this initial highly contaminated roof water away from the cistern. Once the catchment surface has been washed off by an adequate amount of rainfall, the roof water is once again routed to the cistern for storage. Usually the first 0.01 inch of rainfall is considered adequate to remove most of the dust and dirt from the surface of the catchment. In this way, only the cleanest roof water is collected in the cistern, whereas the contaminated roof wash is discharged to waste.

There are several ways of accomplishing this objective. The roof water can be diverted manually through a series of valves within the spouting system, or automatic roof washers may be fabricated by the cistern owner or purchased from commercial distributors.

A simple roof-wash diverter is shown in Figure 2.12. This particular design requires manual operation of a flap valve to control the flow path of the roof water within the spouting system. Such a valve would be necessary on each downspout unless they all converged into a single pipe just before emptying into the cistern. The single-valve arrangement is definitely preferred since the operation of this type of diverter requires that someone go out and close the valve shortly after the rain begins, allowing the roof water to flow into the cistern. The valve should be located so that it can be reached or controlled from a covered porch or other roofed area adjacent to the house or cistern.

During periods when rains are separated by only brief periods of time (less than a day), it is not necessary to divert the initial roof wash every time it begins to rain. However, it is important to divert the initial roof water produced by the first rainfall following an extended dry period. This requires returning the diverter to the rinse position following each storm to ensure that dirty water isn't accidentally added to the cistern.

Figure 2.12. A simple roof-wash diverter.



Determining how much roof water to allow to run to waste before routing it to the cistern will vary for each storm. You can use the visual appearance of the roof water as an indicator—if to your eye it runs clear when collected in a clear glass jar, you can direct the water to the cistern for storage and subsequent use. Or you can place a large 10- to 20-gallon container under the downspout draining to waste. The container should be sized to suit your particular roof area—10 gallons per 1,000 square feet of roof area.

At the beginning of a rainstorm, then, the dirty roof water is directed into the container, and when it is full you know that the catchment has been sufficiently rinsed and the roof water can thereafter be routed to the cistern. For this type of arrangement, a single roof-water collection vessel for the entire catchment is best. Adequate drainage, such as into a gravel-filled hole (well removed from the cistern), should be provided for the roof water that is to be wasted, whether or not it passes through a collection vessel first.

There are also automatic roof-wash diverters that do not require someone's presence to operate at the start of a rainstorm. The basic principle is the same. A certain quantity of contaminated roof water at the beginning of a rainstorm is collected in a vessel so that it cannot enter the cistern. Once the catchment has been rinsed off by a sufficient quantity of water, the roof water is again routed to the cistern. As with manual systems these should be inspected after each storm to ensure they perform properly during the next storm.

Roof-water filters

In addition to roof washers, your roof-catchment system should include a roof-water filter located between the catchment and cistern. Such a filter serves primarily to remove gross particulates and associated contaminants from the water before it enters the cistern. It can also serve to neutralize the acidic rainwater to some extent if limestone is used for the gravel and stone portions of the filter.

One possible design for a roof-water filter is pictured in Figure 2.11. The filter box can be totally or partially buried underground to lessen the chances of freezing during the winter months. The filter box shown in Figure 2.11 is made of reinforced concrete with walls and top a minimum of 4 inches thick. A short section of precast concrete culvert pipe can also function as a filter box; a lid or top is required, however. A manhole and cover similar to that described previously for the cistern itself should also be built into the top of the filter box to provide access for periodic inspection and maintenance. If the filter box is positioned directly on top of the cistern, as shown in Figure 2.11, be certain that there is a watertight seal where they join.

Several layers of gravel and sand make up the filtering medium. The total thickness of the filtering materials should be a minimum of 12 inches and a practical maximum of around 3 feet, depending on the area of the catchment and the size of the filter box. A filter the size of that shown in Figure 2.11 is adequate for a roof area of up to 2,000 square feet for all but perhaps the most intense rainfalls. For this reason, an overflow should also be built into the filter box, as shown in Figure 2.11. Mesh hardware cloth (¼ to ½ inch) or aluminum screening is placed on the bottom of the filter box (on the inside) before the gravel and sand are added. This keeps the filtering material in place. Also keep in mind that clean sand and gravel must be used, and the entire filter box should be cleaned and disinfected with chlorine.

A perforated splash plate should be located approximately 2 inches above the top of the sand. This serves to break the force of the incoming water, spreading it evenly over the top of the filter sand. In this way the sand is disturbed as little as possible. A nonmetallic material such as wood or plastic should be used as a splash plate. Half-inch holes should be drilled through the splash plate on 2-inch centers. Supports for the splash plate should be built into the wall of the filter box, thus allowing for easy removal and refitting of the plate for inspection and maintenance of the filter.

Any filter tends to clog over time and requires periodic maintenance. This may entail removing portions of the filter medium and replacing them with new sand or gravel. Whenever such replacement is necessary, the entire filter box should be cleaned and disinfected following the procedure described earlier. Periodic inspection of the roof-water filter in your system should provide visual evidence of a malfunction or clogged condition requiring remedial action.

Roof catchments

As mentioned previously, certain types of roofing materials are more suitable than others for use as collection surfaces for rainwater cisterns. Those most suitable for catchments are asphalt shingle, slate, and sheet metal (tin or aluminum). Consider the following factors when planning a roof-catchment cistern system:

- Rough-surfaced roofing materials collect dirt and debris, which will affect the quality of the runoff.
- Some painted surfaces, some wood shingles, and some asphalt shingles may impart objectionable tastes or colors.
- All gutters and downspouts should be easy to clean and inspect.
- The roof area should be large enough to supply the amount of water needed.
- The atmosphere in your area may contain undesirable or harmful pollutants that might affect the quality of collected rainwater.
- Before using a roof coating, consult local health authorities concerning possible toxicity of the material.
- The National Sanitation Foundation (NSF) has established a certification for materials used in water collection systems. NSF provides this listing of roofing materials on its web site at www.nsf.org (search their site for "Rainwater Collection" to find the listing).

Gutter guards should also be installed along any roof catchment. Aluminum screening of ¼-inch or ½-inch mesh hardware cloth can be cut into strips and secured over the top of open gutters. Gutter guards will keep leaves, twigs, and animals out but let water in. Also remove any tree limbs overhanging the catchment. You may also want to remove nearby trees that contribute leaves and twigs to the catchment; or, if you're planning a new home and cistern system, don't plant trees right next to the house.

Treating Cistern Water

Several of the design features described previously will help ensure good-quality cistern water. These include roof washers, roof-water filters, gutter guards, water force breakers, and effectively screened cistern inlets and outlets. In addition to these measures, however, specific water treatment will be necessary to ensure safe, potable cistern water. Recommendations for disinfecting cistern water and minimizing corrosion and sediment transport within distribution systems is covered in the following sections.

Disinfecting cistern water

Scrub down the interior of the new cistern with a disinfecting solution of chlorine and water, as described for roof-water filter boxes. CAUTION: Make sure there is adequate ventilation while working inside the cistern because of the dangers of chlorine gas and lack of oxygen. Following the disinfecting operation and before filling with water, rinse down the cistern interior with clean water until the strong odor of chlorine is no longer present. A cistern should also be disinfected following cleaning or other maintenance that requires emptying the cistern.

To disinfect stored cistern water the simplest procedure is to add 5 percent chlorine bleach once a week, at a rate of one ounce per 200 gallons of stored water during dry periods, or one ounce for each 400 gallons of stored water during wet spells. If a chlorine taste develops in the water it may be reasonably safe to dose weekly with one ounce for each 400 gallons of stored water. If, due to the absence of occupants, water is not chlorinated for a week or longer, one ounce of chlorine bleach for each 200 gallons of stored water should be added to the cistern when the occupants return.

You can devise a simple way of measuring the volume of water stored in your cistern. Obtain a wooden pole, long enough to reach the bottom of the cistern through the manhole opening. The pole can then be calibrated such that when it rests on the bottom it will indicate the approximate volume of stored water from the depth of the water. This can be done in the following way. First, find the capacity of the cistern by multiplying the length by the width by the depth (all in feet) to get the number of cubic feet of storage. Then multiply this figure by 7.5 to get the number of gallons of storage capacity. For example, a cistern measuring 10 feet by 8 feet, with a depth of 6 feet, would have a storage capacity equal to (10 X 8 X 6) X 7.5, or 3,600 gallons.

Once you have determined your cistern's capacity, you can calibrate the pole according to the following example. To calibrate a measuring pole for a cistern measuring 10 feet by 8 feet, with a depth of 6 feet, first divide the capacity by the depth in inches to obtain the number of gallons per each 1-inch thick layer of stored water (3,600/72 or 50 gallons in this example). Then simply mark the pole at 1-inch intervals, starting at one end and going toward the other until the total depth of the stored water is reached (6 feet or 72 inches in this example). At each 1-inch interval mark the corresponding volume, starting (at the bottom) with 50, 100, 150, 200, etc., adding 50 (for this example) to each successive interval.

Once calibrated, such a measuring stick gives you a quick way to estimate the volume of water remaining in the cistern at any given time. Depths and corresponding volumes also can be listed side by side in a simple table, and the stick is then only used to measure the depth of water in the cistern. Chlorine dosage required can also be listed alongside the various volumes for quick reference.

If the water has a disagreeable taste and odor, add 2 ounces of crystallized sodium thiosulfate (available from Fisher Scientific or other supply houses) to 1 gallon of clean water. Then add 1 quart of this solution to each 1,000 gallons of water in the cistern, mixing it with the cistern water but being careful not to stir up bottom sediment. After a few hours the water should be free of the disagreeable taste and odor.

Any water supply should be tested for bacterial contamination at least once a year. If a water analysis shows that the water is contaminated, a careful examination of the entire water supply system and of the area surrounding the cistern has to be made in order to find and eliminate the source of contamination.

As an alternative to adding disinfectant directly to the cistern, commercially distributed in-line automatic chlorinators and ultraviolet lights are available from most distributors of water-conditioning equipment.

Minimizing corrosion within cistern water systems

As pointed out previously, rainwater is acidic and therefore corrosive. Unless steps are taken to neutralize this water, it will corrode household distribution systems and add toxic metals such as lead and copper to the tapwater. Corrosion processes are very complex chemical reactions that involve many different factors. Following the recommendations presented here will not completely eliminate corrosion within your cistern system but should reduce it to tolerable levels.

Perhaps the surest way of minimizing tapwater metals is to use plastic pipe to service at least one cold-water tap within the system. This would effectively replace the source of metallic lead and copper (lead-soldered copper systems) with a nontoxic, noncorrodible conduit of PVC plastic. Be sure to use plastic pipe that meets specifications for conveying drinking water, if that is what you intend to use it for. If just one cold-water tap within your household were to be serviced by an all-plastic water line, then you should draw all of your drinking water from the tap and from no other. It would probably be best to plumb the kitchen cold-water tap and perhaps a bathroom lavatory with plastic. If you are planning a new system from scratch, then you may want to consider using plastic plumbing throughout the entire distribution system.

If your existing distribution system is composed of lead-soldered copper plumbing throughout, and you do not want to replace a portion of it with plastic, an alternative is to install an in-line acid neutralizer to reduce the water's corrosivity. Such units are available commercially from water treatment equipment distributors located throughout Pennsylvania. The acid-neutralizing units are in the $1,000 price range and are available in either manual or automatic models.

In lieu of an in-line acid neutralizer, a neutralizing agent can be added directly to the cistern. It would be necessary to add the appropriate amount of neutralizing agent at periodic intervals, depending on the amount and frequency of rainwater input to the cistern. For example, approximately 2 ounces of pulverized limestone can be added to each 1,000 gallons of rainwater to neutralize the acidity. Perhaps the most convenient treatment procedure is to add the neutralizing agent when you add disinfectant to the cistern (once a week), at least during weeks when additional rainfall is collected. During weeks when little or no fresh rainwater is collected, it would not be necessary to add more neutralizer to the cistern.

Some cistern owners place blocks of natural limestone in their cistern to serve as continuous neutralizing agents. We have no guidelines to offer you as to the size or other characteristics of such blocks.

Regardless of whether or not you install an acid neutralizer or plastic pipe, or add a neutralizing agent directly to the cistern, there is one simple thing that you should do before using the tapwater for drinking and cooking purposes. Always allow the cold water to run for about a minute before using it for drinking or cooking. This flushes the "stale" water (laden with metals if from lead-soldered copper or other metallic pipe) from the supply line, leaving you with tapwater of acceptable quality. This practice is especially important after a tap has gone unused for several hours, or overnight. Rather than just letting the water run down the drain during this procedure, you may use it for purposes other than drinking or cooking.

Minimizing sediment transport through cistern systems

Using roof washers and roof-water filters, described in detail earlier, minimizes the input of particulates or the formation of a sediment layer on the cistern bottom. Therefore, certain steps need to be taken to prevent this sediment from being transported through the distribution system and possibly reaching the tap.

Periodically cleaning the cistern to remove the sediment accumulation is recommended. This involves draining the cistern, scooping out the sediment, and washing down the interior with a brush and disinfectant. Before refilling the cistern, thoroughly rinse it with clean water. Such cleaning should be done at regular intervals every three to five years. Applying a new coat of interior sealant may also be necessary at the time of cleaning. Don't forget to set aside enough water to operate the household while the cistern is out of commission.

A simple, cartridge-style sediment filter should be installed between the cistern and tap to remove any sediment that might otherwise be transported to the tap.

Groundwater quality is a concern in many areas of the state. Contrary to popular belief, natural groundwater is not always free of pollutants and impurities. Some pollutants occur naturally when water interacts with impurities in the rock layers encompassing an aquifer (Figure 3.1). For example, hard water deposits from calcium and magnesium are common in groundwater from limestone aquifers, while hydrogen sulfide (which causes the rotten-egg odor), iron, and manganese often occur in certain sandstone and shale aquifers. Some aesthetic problems can cause additional drinking-water problems as well. Aggressive water from acidic sandstone and shale can cause the lead and copper to dissolve from household plumbing, leading to toxic concentrations capable of causing serious health effects in humans.

Human activities can also pollute groundwater aquifers. This pollution may originate from point sources (e.g., a pipe discharging into an aquifer) or, more often, from nonpoint sources (e.g., diffused flow from lawns, septic systems, and farm fields). Many groundwater pollutants from human activities cause adverse health effects (Figure 3.2). Coliform bacteria and *E. coli* bacteria commonly found in human or animal wastes can cause flulike illnesses if they are consumed in drinking water, while nitrates from fertilizers can cause blue-baby syndrome in infants. Also worth noting is that some of the naturally occurring pollutants discussed above, such as iron, manganese, and sulfate, can also come from mining or other human activities.

Figure 3.1. Frequency of pollutants causing aesthetic problems in private groundwater wells in Pennsylvania. *(From Sharpe et al. 1985; Swistock et al. 1993; Swistock et al. 2009)*

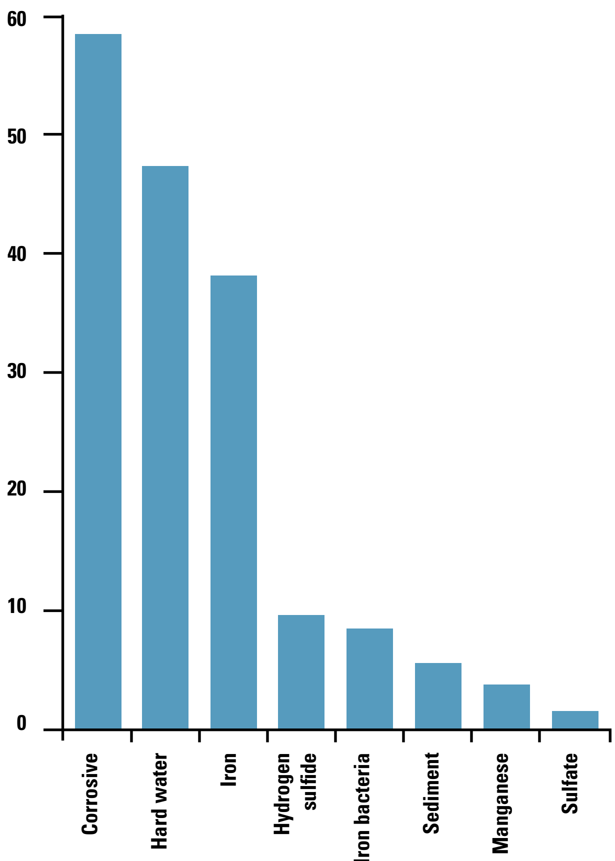
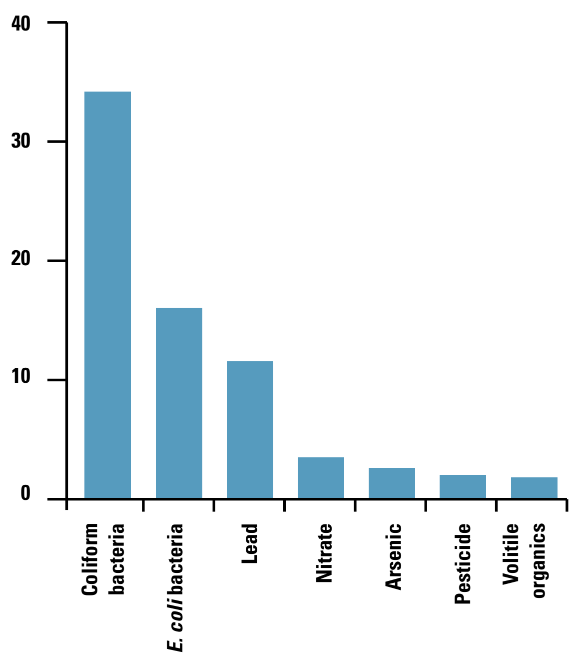


Figure 3.2. Frequency of various health-related pollutants in private groundwater wells throughout Pennsylvania. *(From Sharpe et al. 1985; Swistock et al. 1993; Swistock et al. 2009)*



WHAT CAN YOU DO TO PROTECT GROUNDWATER?

Some simple actions can help to ensure the future availability and health of Pennsylvania's groundwater resources:

- Do not apply fertilizers, herbicides, or other chemicals within 100 feet of wells or springs on your property. Reduce the use of these chemicals on other areas of your property.
- Use up household chemicals according to the label or dispose of them at hazardous waste drop-off locations rather than in the household garbage.
- Get your well or spring tested annually by a state-certified water-testing laboratory to detect local problems before they can contaminate the entire aquifer.
- Properly construct and maintain your on-lot septic system to prevent groundwater contamination.
- Properly seal any unused well that may exist on your property.

In Pennsylvania, many public water suppliers have developed wellhead protection programs to protect the areas of land that directly influence the quality of the local groundwater supply. It is the responsibility of each private water system owner to protect the land area that supplies water to his or her home drinking-water system. Groundwater is often polluted by the following activities:

- Improperly sealing unused wells
- Septic system malfunction or failure
- Gas or oil well drilling
- Illegal roadside dumps or improperly managed landfills
- Application of fertilizers, pesticides, herbicides, insecticides, and animal wastes
- Surface or deep coal mining
- Chemical spills from nearby industry
- Failing underground storage tanks
- Highway salt or salt storage piles
- Saltwater intrusion

This chapter explores the more common causes of human-made groundwater contamination affecting private water wells in Pennsylvania.

UNUSED WELLS

Many states have very specific water-well construction standards. Regulations often include a section ensuring that all unused wells be properly decommissioned by a certified professional. In Pennsylvania, guidelines exist only for public wells, but it is still very important that old unused wells be taken care of so they do not pose a hazard for those using the property and do not serve as a conduit for surface water to contaminate local groundwater resources. For more information on the proper procedures for sealing an unused well, refer to Chapter 2.

SEPTIC SYSTEM MALFUNCTION OR FAILURE

The 1990 U.S. census reported that one out of every four homes in Pennsylvania, or approximately 1.2 million homes, made use of an on-lot septic system for wastewater management. Homeowners who make use of both private water systems and on-lot septic systems should make certain that the distance between the two is adequate and that, ideally, the water supply is not downslope from the septic system or leach field. It is also very important that all on-lot septic systems receive proper routine maintenance to ensure that no system failures occur, which could affect the home's drinking water quality. A properly located and maintained on-lot system should pose no threat to a private drinking water supply.

In general, most on-lot septic systems treat wastewater in two stages, or sections. The first section consists of a septic tank (where solids are removed), and the second section consists of a soil absorption area (where liquids can percolate through the soil). As is true of a private water system, an on-lot septic system must be maintained periodically by the homeowner to ensure that it continues to function properly. Pennsylvania has regulations for the construction of new septic systems, but the maintenance schedule usually falls on the homeowner's shoulders. For this reason, many people do not maintain the system until there is a malfunction or complete failure.

If a septic system malfunction does occur, it could cause wastewater to back up into the house, pond on the land surfaces surrounding your seepage area, or discharge to groundwater, contaminating local water resources (including nearby wells and springs). To prevent this from happening, it is important for rural homeowners to conduct routine maintenance (assuming the system was designed and constructed properly).

How Do I Maintain My Septic System?

The easiest thing you can do to maintain your on-lot septic system properly is to conserve water used in and around the home. Septic systems function better with less water entering the system. In fact, a malfunction (hydraulic overload) can actually be caused by too much water entering the system. Installing water-conserving appliances and adopting simple water-conserving habits at home will help keep your system working properly.

Another key component of proper maintenance involves having your septic tank pumped out periodically. Most township ordinances and Penn State experts recommend pumping at least every 2-3 years. Pumping at this interval ensures that your system is cleaned out and ready to function the way that it was intended.

Other things that will help to keep your on-lot septic functioning properly include: (1) avoiding planting trees or removing roots in or near the soil absorption area, as they may interfere with the system, (2) not adding any chemicals or antibacterial agents to the system, and (3) avoiding the use of a garbage disposal.

For more information on on-lot septic systems, visit the Penn State Water Resources Extension Web site at water.cas.psu.edu or contact the Pennsylvania Septage Management Association at www.psma.net.

GAS WELL DRILLING

Gas well drilling has occurred for decades in much of western and northern Pennsylvania, with thousands of new and active gas wells in the state (Figure 3.3). Most of these wells tap gas reserves a few thousand feet below the earth's surface. With discoveries of new gas reserves in the Marcellus shale and new drilling technologies to reach previously untapped gas reserves, both the number and depth of gas wells are expected to rise dramatically over the next decade. As a result of renewed interest in gas drilling in Pennsylvania, a survey of private water well owners in the state during 2007 found that 13 percent felt that gas well drilling was the biggest threat to their water supply.

Potential Impacts on Private Water Supplies

Gas well drilling has the potential to cause occasional problems in both the quality and the quantity of water from nearby private water wells and springs. Gas wells produce polluted waste fluids from naturally occurring brines (water stored deep underground with high salt and metals concentrations). Newer drilling also relies on hydrofracturing, in which a mixture of water, sand, and chemicals is injected into the ground to fracture the rock and allow the escape of the tightly held methane gas. Hundreds of thousands of gallons of hydrofracturing fluids may return to the surface accompanied by new pollutants from deep underground. Pollution of private water supplies from gas well activity has been documented primarily from absent or corroded well casings on older or abandoned gas wells. Groundwater pollution has also occurred from flooded or leaking brine holding pits, accidental discharge of brines to the land surface, and spills of drilling chemicals and fuels at the drilling site.

Figure 3.3. A typical gas well site in McKean County, Pennsylvania.

Groundwater Pollutants from Gas Wells

Waste fluids from gas well drilling are highly mineralized and contain levels of some pollutants that are far above levels considered safe for drinking water supplies. As a result, even small amounts of brine pollution can result in significant impacts on drinking water supplies. The most common pollutants are salts (sodium and chloride) and various metals including iron, manganese, barium, and arsenic. Other pollutants associated with gas well waste fluids are specific conductance, alkalinity, total suspended solids (turbidity), hardness, calcium, magnesium, coliform bacteria, strontium, surfactants/detergents, sulfate, oil/grease, total organic carbon (TOC), and volatile organic compounds (VOCs) such as benzene.

A final problem that can be associated with gas drilling, or can occur naturally, is methane gas migration into water wells and springs. In this case, the methane gas rapidly escapes from the groundwater and may pose an explosion hazard in confined spaces. Methane in water usually creates obvious symptoms of effervescence and spurting faucets owing to gas buildup.

A study of 200 private water wells by Penn State and McKean County Cooperative Extension in 2007 found that 1 to 3 percent contained elevated levels of pollutants that could originate from gas drilling (see Figure 3.4). It is important to note that this study did not attempt to differentiate between effects from past versus current gas well drilling. Given the changes and strengthening of regulations on gas well drilling that occurred in the mid 1980s, it is likely that most of the groundwater contamination found in McKean County occurred from past drilling practices. Still, these results point to the importance of remaining vigilant in properly testing and monitoring private water supplies near gas wells using the strategies outlined later in this discussion.

Data from various regulatory agencies responsible for enforcing gas well drilling regulations indicate that more than 95 percent of complaints received by homeowners suspecting problems from recent nearby gas well drilling are, instead, due to preexisting problems or other land-use activities.

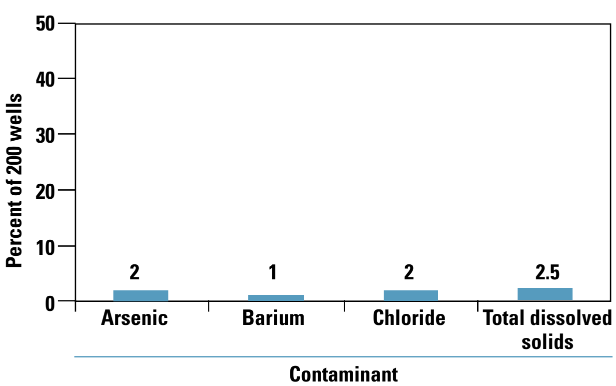
Strategies to Protect Water Supplies from Gas Drilling

State regulations are in place to minimize the impacts of gas drilling on water resources. There are setback distances that limit how close a gas well can be drilled to any water supply. Gas drilling companies must install a strong casing and cement (called the "freshwater protection string") to protect groundwater resources from contaminants moving through the gas well borehole. They must also collect waste fluids in plastic-lined pits and deliver the waste fluids to approved treatment facilities. Despite these protections, occasional problems still can occur.

There are various steps you can take to protect your water supply from gas drilling impacts. These include:

- *Learn when and where drilling will occur*—Some homeowners learn of nearby gas well drilling plans through lease agreements or through required notification by certified mail if their water supply is within 1,000 feet of the proposed well. But anyone can be kept abreast of gas well drilling plans through the eNotice feature on the Pennsylvania Department of Environmental Protection (DEP) Web site. The eNotice provides permit information, but it requires a significant investment of time to learn.
- *Control seismic testing*—Before drilling wells in an area, gas companies often seek permission from land owners to do seismic testing to determine the thickness of gas-bearing rocks and other geologic information. If explosives are to be used in seismic testing, make sure to stipulate that each shot hole is promptly and properly decommissioned to prevent groundwater contamination by surface water. Also stipulate that explosives not be used within several hundred feet of a private water well or spring to ensure that water flow is not altered.
- *Get your water tested*—Before gas well drilling takes place, drinking water supplies within 1,000 feet of the proposed gas well will likely be tested at no charge to the homeowner by a certified testing laboratory hired by the gas company. Make sure to arrange to receive the results of this testing in a timely manner from the commercial laboratory. If your water supply is more than 1,000 feet from a proposed gas well site OR if you simply want to confirm the results collected during the predrill survey, you must arrange to have your water tested at your expense. It is always a good idea to have your own independent water analysis for comparison.

Figure 3.4. The percentage of 200 private water wells in McKean County, Pennsylvania, that failed drinking water standards for come common pollutants associated with gas well drilling. *(Clark et al. 2007)*



Remember that water samples to document impacts from gas well drilling generally should be collected by an unbiased, professional representative from a state-certified water-testing lab. This adds significantly to the cost of water testing but is vital for the admissibility of the results in any legal action related to polluted private water supplies. Most local state-certified water-testing labs provide specific gas drilling packages that include pollutants that can result from drilling activity. You can expect to pay $200 to $500 or more to have a predrilling water sample collected and analyzed by a certified water-testing laboratory, depending on the complexity of the test package. More information on water-testing strategies can be found in Chapter 4.

- *Pay attention to symptoms of problems*—During or after nearby gas well drilling, there may be obvious changes to your water supply that warrant filing a complaint to the Pennsylvania Department of Environmental Protection (DEP). Common symptoms include water foaming, muddiness, bubbling, spurting faucets, metallic or salty taste, fuel or oil smell, and a reduction in water flow. Should you notice any obvious changes in your water supply in conjunction with nearby gas well drilling, you can file a complaint with the regional DEP office. They will investigate the claim within 10 days and make a determination of the cause within 45 days. Complaints filed during gas well drilling operations or within six months after drilling is completed place the burden of proof on the gas well operator. Complaints filed more than six months after drilling has ended place the burden of proof on the homeowner. During the investigation, DEP will obtain results from all predrilling water testing. They may also decide to collect additional water samples as part of the investigation.

- *Document well and spring flow before drilling*—Diminished or lost water supplies resulting from gas well drilling have occurred but are rare. When this does happen, it is usually an obvious, complete loss of water rather than a subtle decrease in water yield. Well and spring owners who wish to document water supply conditions before and after gas well activities need to hire a professional water well contractor or hydrogeologist to measure and document these conditions independently. You can find a list of local water well contractors certified by the National Ground Water Association (NGWA) at www.wellowner.org.
- *Include water resource protection in your lease*—Many of the aforementioned ideas for protecting a water supply can be stipulated in a gas leasing agreement (if a lease is offered by the gas company). The lease agreement allows a homeowner to set rules for the gas company to follow in order to access private property. For example, you can stipulate setback distances, water testing, or flow measurement in your lease agreement.

More information on gas well drilling can be found at www.depweb.state.pa.us; choose keywords, "Oil and Gas."

ROADSIDE DUMPS

Unfortunately, in rural areas throughout Pennsylvania, illegal roadside dumps exist. These provide a cheap and easy way for individuals to dispose of appliances, furniture, hazardous materials, and other trash. Although convenient for the homeowner, such a dump is an eyesore as well as a hazard for those enjoying our natural areas and can often negatively affect local surface and groundwater quality.

Landfills exist for the disposal of waste materials in a way that poses minimal risk to the environment. When roadside dumps are used out of convenience, there is no way of knowing if or when hazardous materials could leach into nearby surface or groundwater supplies.

If you know of or can see an illegal roadside dump close to your home and you are on a private water supply, make sure to test your water regularly to monitor for possible contaminants entering your water supply. Knowing what to test for can be difficult since the contamination is based on the materials being dumped. If you have an idea of the contents of the dump, you can use that to determine what water tests would be most appropriate. More information on roadside dumps and water quality can be found at pubs.cas.psu.edu/FreePubs/pdfs/UB040.pdf.

AGRICULTURE

Agriculture is one of our most important industries; however, many of the practices associated with agricultural operations can affect groundwater quality. Removing plant cover from the soil can cause erosion. Nutrients, sediment, pathogens, and residues from pesticides or fertilizers can run off into streams or enter groundwater. While the agricultural industry and small farmers do not intentionally pollute our surface and groundwater supplies, such pollutants can end up in private water systems.

It is often not easy for a homeowner to pinpoint the source of contamination from nearby agricultural operations. If you suspect that your drinking water is being affected by a nearby farm, try contacting the landowner to see if he or she can give you information about what chemicals are used on the farm. This will help you select the appropriate water tests.

In general, private well water potentially affected by agricultural activities should be tested regularly for total coliform bacteria, *E. coli,* and nitrates. If you can obtain information about which specific pesticide or fertilizers were used, these tests can be added.

MINING

Pennsylvania has a long history of mining. Mines were largely underground until the 1960s, when stripmining technology was developed to access minerals from the surface. Early coal mining regulations were lax, resulting in significant pollution of both surface and groundwater resources, especially in western Pennsylvania. In areas where coal mining has occurred, private water wells and springs may have acidic water that is contaminated with high levels of iron, manganese, aluminum, and sulfate. If you live in a mining region, you may notice poor-tasting water that causes various staining and odor problems as a result of nearby abandoned mines.

Strengthening of mining regulations during the 1970s included protections for private water supplies near active mining sites. These regulations include a requirement that, in certain cases, water supplies proven to be contaminated by active mining be replaced. If you are concerned about historic or proposed mining in your area, consider having your water tested for pH, sulfate, iron, manganese, and aluminum.

WATER-TESTING BASICS

If you've had your water tested, you probably did so to find out if it is safe for drinking. Even if your water tastes, smells, and looks fine, water testing is necessary because many contaminants have no obvious odors or tastes. In other cases, where a water-quality problem is obvious, testing can determine the exact concentration of the pollutant to assist in determining the best solution to the problem.

Water testing is especially necessary if your house is served by a private water system, because some of these systems have water-quality issues. Private water systems include drilled wells, dug wells, springs, or cisterns that serve an individual home. There are no regulations or laws requiring water testing, system maintenance, or water treatment for these water supplies. Rather, owners must voluntarily arrange for water testing and must voluntarily correct any problems to provide safe drinking water. Regardless of whether your water supply is private or public, the information in this chapter will help you interpret water test results.

If you live in a community served by a public water supply (i.e., one source of water for multiple customers), then the water company already does water testing for you. Public water suppliers are required by law to routinely test their water and treat it to meet water-quality standards. They are also required to issue water test reports to their customers on a regular basis. This chapter may be helpful in interpreting these reports as well.

Although drinking water standards are applicable to all types of water supplies, they are not legally binding for private water supplies. It is recommended, however, that private water supply owners maintain their water quality by the same standards required by law for public water supplies.

Why Test Your Drinking Water?

More than one million homes in Pennsylvania are served by private water supplies (wells, springs, or cisterns). Homeowners with this type of water supply should consider having it tested for the following reasons:

1. Unlike public water systems, private water supply testing is the homeowner's voluntary responsibility. No government agencies or programs routinely test private water systems for homeowners.
2. Surveys indicate that about half of private water supplies have never been tested by a state-certified laboratory.
3. Additional studies have found that about 50 percent of private water systems fail at least one drinking water standard. In fact, surveys have shown that only about 20 percent of homeowners with unsafe drinking water are aware of the problem.
4. Many pollutants found in private water systems have no obvious indicators (such as smell or taste) and can only be detected through laboratory testing.
5. Water testing is generally economical and convenient, with many testing laboratories located throughout the state.
6. Water testing provides vital information to document the quality of your drinking water. Data from previous tests may be necessary if you ever need to prove in court that a nearby land use has damaged your drinking water quality.
7. The only way homeowners can be certain that their water is safe to drink is to have the water tested periodically.

Tests to Have Done Routinely

While it is possible to have a water supply tested for many things, such tests are very expensive and often unnecessary. Instead, homeowners should focus testing on a few standard parameters along with additional tests related to nearby land uses.

Private water supplies should be tested every year for total coliform bacteria and *E. coli* bacteria. Bacteria are more likely to be present during wet weather conditions. For this reason, testing for total coliform every 14 months will ensure that the testing is done at different times of the year. Coliform bacteria includes a large group of many types of bacteria that occur throughout the environment. They are common in soil and surface water and may even occur on your skin. Large numbers of certain kinds of coliform bacteria can also be found in waste from humans and animals. Most types of coliform bacteria are harmless to humans, but some can cause mild illnesses and a few can lead to serious waterborne diseases.

If coliform bacteria are found in a water supply, a follow-up test can be done by the laboratory to look for *E. coli*—a type of coliform bacteria found only in human or animal wastes. A positive *E. coli* result is much more serious than coliform bacteria alone because it indicates that human or animal waste is entering the water supply.

Drinking water should be tested for pH and total dissolved solids (TDS) every three years. These tests are similar to a doctor taking your temperature—they are general tests that provide an index to the quality of your drinking water.

Water with a pH lower than 6.5 or greater than 8.5 can cause corrosion of lead and copper from household plumbing and bad tastes. The total dissolved solids (TDS) content of drinking water should be below 500 milligrams per liter (mg/L), and the value should not change much from one test to the next. Increases in the TDS of water could indicate that pollution has occurred, warranting further, more detailed, testing.

Additional Testing

Tests Related to Local Land Uses

Every three years, additional testing should be done related to land uses occurring or expected to occur within sight of the home. Pollutants associated with various common land-use activities in Pennsylvania are shown in Table 4.1. Keep in mind that not all laboratories are able to run all of these tests.

Tests Related to Obvious Symptoms

Sometimes obvious stains, tastes, or odors in water prompt a homeowner to seek water testing. Many pollutants that cause obvious aesthetic problems occur naturally in groundwater, but some can come from land uses, especially mining. While the presence of these pollutants is apparent from their symptoms, testing through a certified laboratory is valuable to confirm the pollutants and provide valuable information about their form and concentration. This information is helpful when determining the best options for treatment. Some common drinking water symptoms and their associated pollutants are given in Table 4.1.

Where to Test Your Drinking Water

Always have your water tested by a state-certified water-testing laboratory. The Pennsylvania Department of Environmental Protection (DEP) certifies water-testing laboratories in Pennsylvania to ensure they are using analytical procedures designed to give accurate test results. Be sure to ask if the lab is certified and what tests it is certified to perform every time you have your water tested. Laboratories are reevaluated periodically, and their certification status may change. You can obtain a list of certified labs from your county Penn State Cooperative Extension office, online at water.cas.psu.edu, or from your local DEP office. Also, your local DEP office can arrange for bacteria testing through the state DEP laboratory.

Be cautious of water test results from uncertified labs. In addition, be cautious of water test results from salespeople and others who say they have their own laboratories or who try to test water at your residence. Always have these tests confirmed by a certified laboratory and, if possible, interpreted by a knowledgeable and neutral third party before taking corrective action.

Once you have received your water test report from the laboratory, you're ready to interpret exactly what it means. The sample water test report shown in Figure 4.1 (page 38) will get you started by familiarizing you with the information presented in the report.

Table 4.1. Common drinking water problems and their symptoms (left) and land use causes (right).

Symptom	Test
Orange-brown stains, metallic taste	Iron, manganese
Black flecks or stains	Manganese, iron
White or gray film, increased soap use, damaged hot water heater	Hardness
Salty taste	Chloride
Blue-green stains, metallic taste, especially early in morning, small leaks in metal plumbing	pH, corrosivity index, copper, lead

Land use	Test
Mining	Iron, manganese, sulfate, aluminum
Gas or oil well drilling	Chloride, barium
Industry	Organic scans
Gas stations	Petroleum products
Road deicing	Sodium, chloride
Homes with septic	Nitrate, bacteria
Agriculture	Nitrate, pesticide scans

Collecting Water Samples

Who Should Collect Water Samples?

Homeowners can usually collect water samples themselves, after obtaining properly sanitized containers and instructions from the laboratory. Some rare, specialized tests, such as those for radon, *Giardia*, *Cryptosporidium,* and hydrogen sulfide, usually require that a lab employee visit your home to collect the sample.

In special circumstances where legal action could follow, it is best to have samples collected by an unbiased professional. For example, samples intended to document existing drinking water quality prior to mining, gas well drilling, or other land-use disturbances should be collected by a qualified third party. This adds to the cost of water testing but is vital for the admissibility of the results in any legal action related to polluted private water supplies.

Procedures

Most water samples are collected at the kitchen faucet since this is where most water is used for drinking and cooking. If you already have treatment equipment installed in your home, keep in mind that collecting a water sample from a kitchen or bathroom faucet is often influenced by the treatment equipment. If you are interested in determining the raw water quality from your well (as it emerges from the ground), you may wish to collect a sample before the water enters any water treatment equipment or the home plumbing.

Do not use food or drink containers to collect or take water samples to a laboratory! Instead, arrange to obtain properly sanitized containers and instructions from the laboratory ahead of time. The sample collection instructions provided by the laboratory must be followed carefully in order to ensure an accurate test result. In general, before taking the water sample, you should rinse the container two or three times with the water being collected. However, testing labs often supply containers that have a fixing compound preventing the loss or breakdown of a certain chemical. In this case, if the bottle is rinsed or allowed to overflow, the fixing agent will be removed. For this reason, read and follow sampling instructions carefully.

Special Instructions for Bacteria Samples

For bacteria testing, use a sterile container and clear all chlorine from the water system. Containers supplied by water-testing labs have a chemical present to remove any chlorine residual in the sample. Many labs recommend removing the aerator from the faucet and sterilizing the end of the faucet with a flame or rubbing alcohol before collecting the water sample.

Allow the water to run for a few minutes before collecting the water in the sample bottle. Remove the cap from the bottle, but take care to avoid contaminating the cap or the bottle. Do not set the cap down on anything, and do not touch the inside of the cap or the bottle with your hands. It is ideal to wear sterile plastic gloves when performing this procedure. Run water into the bottle, carefully secure the lid, keep the sample cool, and deliver it to the lab within 24 hours. For this specific test, the shorter the time elapsing between collection and analysis, the more reliable the results. Make sure you contact the lab to determine how and when the sample should be shipped or dropped off at the lab to ensure accurate results. Because of the time limits necessary for bacteria sampling, most labs will not accept water samples on Fridays or before holidays.

Special Instructions for Corrosion Samples

To test properly for corrosion, allow the water to stand in the pipes for at least 12 hours and collect a "first-draw" sample. This sample should be taken first thing in the morning before any water has been used. This collects water that has been in contact with the pipes for at least 12 hours and that is most likely to accumulate metals from corrosion.

COMPONENTS OF A TYPICAL WATER TEST REPORT

Pennsylvania has dozens of water-testing laboratories, each with its own way of presenting results. Your water test may not look exactly like the one shown in Figure 4.1 (on the following page), but it probably contains the same basic components. Read about each water test component below and try to find it on your own water test report. The numbered sections below correspond to the circled numbers shown in Figure 4.1.

Remember that these are only the most common components of a typical water test report. Some laboratories include additional information such as the method used for each test (usually an EPA number), the initials of the person who completed each test, and the date each test was completed. This information is generally unimportant to the client unless litigation is planned.

1. Client and Sample Information

Basic information at the top of most water test reports identifies the person who submitted the water sample, where the sample came from, who received it at the laboratory, etc. This is called the chain-of-custody information and could be very important if the results were to be used in any type of legal action.

2. Analysis

All water test reports list the water-quality parameters that were tested. The list includes only those you asked the laboratory to analyze or those the lab rec-

Figure 4.1. A typical water test report. *Supplied by the Penn State Agricultural Analytical Laboratory.*

PENNSTATE

Agricultural Analytical Services Laboratory
College of Agricultural Sciences
The Pennsylvania State University
University Park, PA 16802

Phone: 814-863-0841
Fax: 814-863-4540
Web: www.aasl.psu.edu

Analysis Report For:	Copy To:
Henry Homeowner 123 Farmland Road Waterville PA 11111 **1**	

LAB ID:	SAMPLE ID:	REPORT DATE:	DATE SAMPLED	SAMPLE TYPE:	COUNTY
W00001	Kitchen	3/31/2009	03/18/09	Drinking Water	Centre

WATER ANALYSIS
Agriculture/Septic Report Package (WD04)

Analysis **2**	Units **4**	Your Test Results **3**	Drinking Water Standard[1] Standard	Type	**5** Method
Total Coliform Bacteria	MPN[2] per 100 mL	78	0	Health	SM 9223B
E. Coli Bacteria	MPN[2] per 100 mL	None detected[3]	0	Health	SM 9223B
pH	-	6.1	6.5 - 8.5	Aesthetics	EPA 150.1
Total Dissolved Solids (TDS)	mg/L	396	500.0	Aesthetics	SM 2540C
Nitrate+Nitrite as N	mg/L	2.1	10	Health	EPA 353.2

Water sample failed the drinking water standard for TOTAL COLIFORM BACTERIA. **6**
Water sample failed the drinking water standard for pH.

For more details on your water test results, please see the description of each parameter on the back of this report and any fact sheets that may have been included with your results.

[1]US EPA has established public drinking water standards based on potential health effects (primary standard) or aesthetic effects such as taste, odor and color (secondary standard). For more detail, see description for each analysis on back of report.

[2]Probable number of colonies per 100 mL of water

[3]Detection limit: 1 MPN per 100 mL

ommended for your water sample. The number of parameters can vary from just a few to dozens of tests. Consult other sections of this chapter for a description of each of these tests.

3. Results

The most important pieces of information on your water test report are the actual results the laboratory found for your water sample. The numbers indicate the concentration of each water-quality parameter in your water sample. In some cases, the unit of measure for each test is shown next to the result. In others, the units are shown in a separate column (as in the sample test report in Figure 4.1). The result for each test should be compared to the drinking water standard for that parameter.

Sometimes, a water test result is reported as "ND" (not detected), which means that the lab was unable to detect any of that pollutant with its equipment. Similarly, some results may have a "less-than sign" (<) in front of a number. This result means the sample contained less than the detection level for that test. Detection levels are often set at the permissible drinking water concentration for a particular pollutant. If the less-than symbol (<) appears before a number and the number is equal to the drinking water standard, the water is likely safe to drink for that particular contaminant.

4. Units

Concentrations of pollutants are usually measured in water by a unit of concentration such as milligrams per liter (mg/L), or by a number such as number of bacteria per 100 milliliters of water (#/100 ml). You might see several different measurement units on your water test report. Refer to "Understanding Units" in the next section to learn more about these.

5. Standards

Many laboratories include the specific drinking water standards on the report next to each test result. This allows for an easy comparison of your result with the safe or recommended level for each test parameter. A complete list of drinking water standards can be found in Table 4.2.

6. Comments

Some water-testing laboratories include a brief explanation of your water test results. Specifically, they often list those pollutants that did not meet the drinking water standard. Occasionally, these comments also describe the potential harmful effects of pollutants that exceeded the standard and how these pollutants may be removed from the water.

Table 4.2. Drinking water standards as of April 2000.

Parameter	Standard	Unit
Microbial (all are primary standards)		
Total coliform bacteria	0	bacteria per 100 ml
Fecal coliform bacteria	0	bacteria per 100 ml
E. coli	0	bacteria per 100 ml
Giardia lamblia	0	oocysts
Cryptosporidium parvum	0	oocysts
Inorganic chemicals with primary standards		
Antimony (Sb)	0.006	mg/L
Arsenic (As)	0.010	mg/L
Asbestos	7 million	fibers/L
Barium (Ba)	2	mg/L
Beryllium (Be)	0.004	mg/L
Bromate	0.01	mg/L
Cadmium (Cd)	0.005	mg/L
Chlorite	1.0	mg/L
Chromium (Cr)	0.1	mg/L
Copper (Cu)	1.3	mg/L
Cyanide	0.2	mg/L
Fluoride (Fl)	4	mg/L
Lead (Pb)	0.015	mg/L
Mercury (Hg)	0.002	mg/L
Nitrate (as nitrogen) (NO_3-N)	10	mg/L
Nitrite (as nitrogen) (NO_2-N)	1	mg/L
Nitrate + nitrite (as nitrogen)	10	mg/L
Selenium (Se)	0.05	mg/L
Sulfate (SO_4) (proposed)	500	mg/L
Thallium (Tl)	0.002	mg/L
Volatile organic chemicals (all are primary standards)		
Benzene	0.005	mg/L
Carbon tetrachloride	0.005	mg/L
Chlorobenzene	0.1	mg/L
o-Dichlorobenzene	0.6	mg/L
p-Dichlorobenzene	0.075	mg/L
1,2-Dichloroethane	0.005	mg/L
1,1-Dichloroethylene	0.007	mg/L
cis-1,2-Dichloroethylene	0.07	mg/L
trans-1,2-Dichloroethylene	0.1	mg/L
Dichloromethane	0.005	mg/L
1,2-Dichloropropane	0.005	mg/L
Ethylbenzene	0.7	mg/L
Monochlorobenzene	0.1	mg/L
Styrene	0.1	mg/L
Tetrachloroethylene (PCE)	0.005	mg/L
Toluene	1	mg/L
1,2,4-Trichlorobenzene	0.07	mg/L
1,1,1-Trichloroethane	0.2	mg/L
1,1,2-Trichloroethane	0.005	mg/L
Trichloroethylene (TCE)	0.005	mg/L
Total trihalomethanes	0.08	mg/L
Vinyl chloride	0.002	mg/L
Xylenes (total)	10	mg/L

(Continued)

Table 4.2. Drinking water standards as of April 2000 (continued).

Parameter	Standard	Unit
Microbial (all are primary standards)		
Synthetic organic chemicals (all are primary standards)		
Alachlor	0.002	mg/L
Atrazine	0.003	mg/L
Benzo(a)pyrene	0.0002	mg/L
Carbofuran	0.04	mg/L
Chlordane	0.002	mg/L
2,4-D	0.07	mg/L
Dalapon	0.2	mg/L
Dibromochloropropane (DBCP)	0.0002	mg/L
Di(2-Ethylhexyl) adipate	0.4	mg/L
Di(2-Ethylhexyl) phthalate	0.006	mg/L
Dinoseb	0.007	mg/L
Diquat	0.02	mg/L
Endothall	0.1	mg/L
Endrin	0.002	mg/L
Ethylene dibromide (EDB)	0.00005	mg/L
Glyphosate	0.7	mg/L
Heptachlor	0.0004	mg/L
Heptachlor epoxide	0.0002	mg/L
Hexachlorobenzene	0.001	mg/L
Hexachlorocyclopentadiene	0.05	mg/L
Lindane	0.0002	mg/L
Methoxychlor	0.04	mg/L
Oxamyl (Vydate)	0.2	mg/L
PCBs	0.0005	mg/L
Pentachlorophenol	0.001	mg/L
Picloram	0.5	mg/L
Simazine	0.004	mg/L
2,3,7,8-TCDD (Dioxin)	0.00003	µg/L
Toxaphene	0.003	mg/L
2,4,5-TP (Silvex)	0.05	mg/L
Radionuclides (all are primary standards)		
Alpha emitters	15	pCi/L
Radium 226 + 228	5	pCi/L
Radium 226	20	pCi/L
Radium 228	20	pCi/L
Beta-particle and photon emitters	4	mrem
Radon (proposed)	300	pCi/L
Uranium	30	µg/L
Inorganic chemicals with secondary drinking water standards		
Aluminum (Al)	0.05-0.2	mg/L
Chloride (Cl)	250	mg/L
Color	15	color units
Copper (Cu)	1.0	mg/L
Corrosivity	Noncorrosive	
Fluoride	2	mg/L
Foaming agents	0.5	mg/L
Iron (Fe)	0.3	mg/L
Manganese (Mn)	0.05	mg/L
Odor	3	T.O.N.
pH	6.5-8.5	pH units
Silver (Ag)	0.1	mg/L
Sulfate (SO_4)	250	mg/L
Total dissolved solids (TDS)	500	mg/L
Zinc (Zn)	5	mg/L

Note: Standards in mg/L can be converted to µg/L units by multiplying by 1,000.

WHAT ARE DRINKING WATER STANDARDS?

Drinking water standards give the level of a pollutant that is acceptable in water. These standards are set by the U.S. Environmental Protection Agency (EPA) using available research data. The EPA sets standards for contaminants that are known to occur in water, are detectable in water, and cause a health or aesthetic problem in water. While EPA sets these standards, it is up to the Pennsylvania Department of Environmental Protection to enforce the standards when and where they apply.

Two types of drinking water standards are used: primary and secondary. Primary standards are set for contaminants that cause some health effect such as illness, disease, cancer, or another health problem. Adherence to these standards is mandatory for public water systems, but for private water systems these standards are voluntary. Primary standards are also known as Maximum Contaminant Levels, or MCLs.

Secondary standards are created for water contaminants that cause aesthetic problems such as bad taste, discoloration, or odor. In the past, these standards were always voluntary and were used mainly as guides. Recently, however, some community water systems have been required to meet some of them. Secondary standards are also known as Secondary Maximum Contaminant Levels (SMCLs) or Recommended Maximum Contaminant Levels (RMCLs).

Understanding Units

All drinking water test results and standards have a unit associated with them. These units give the amount of the pollutant per some quantity of water. The most common unit is the milligram per liter (mg/L), which expresses the milligrams of a pollutant in every liter of water. Some laboratories prefer to use parts per million (ppm), which is identical to milligrams per liter. Some contaminants that can be measured in very low quantities are reported in micrograms per liter (µg/L), which is identical to a part per billion (ppb). Keep in mind that concentrations expressed in mg/L (or ppm) can be converted to µg/L (or ppb) by multiplying by 1,000, and that µg/L (or ppb) can be converted to mg/L (or ppm) by dividing by 1,000.

Most pollutants occur in water in very low concentrations. The following examples illustrate just how small these units really are.

- One milligram per liter (mg/L) or part per million (ppm) corresponds to one minute in two years or a single penny in $10,000.
- One microgram per liter (µg/L) or part per billion (ppb) corresponds to one minute in 2,000 years or a single penny in $10,000,000.

Although most water-quality measurements are expressed in these units, some tests such as those for bacteria, corrosivity, turbidity, and radon use different units. To learn more about these other units, refer to the discussions on individual parameters in the following section.

DESCRIPTION OF COMMON POLLUTANTS (by Category)

Hundreds of pollutants can occur in drinking water in Pennsylvania. They can be grouped into four basic categories: microbial, inorganic, organic, and radiological. Although over 100 pollutants have drinking water standards (see Table 4.2 for a complete list), many of these pollutants are uncommon in Pennsylvania. The following sections discuss forty of the most common pollutants in Pennsylvania drinking water. These pollutants are listed alphabetically within the four categories.

Microbial Pollutants

Microbial pollutants include bacteria, viruses, and protozoans. These are living organisms that are visible in water only with the help of a high-powered microscope. Many different kinds of bacteria, some disease-causing but many not, may be present in a water supply. The tests discussed below are specific bacteria tests that are used to determine whether disease-causing bacteria are present in the water. Protozoans are less common in water than bacteria, but a few can pose problems. Viruses are not discussed here because they rarely occur in Pennsylvania drinking water; however, viruses such as hepatitis are carried by water and can cause serious illness.

Coliform Bacteria

Coliform are a large group of bacteria that occur throughout the environment. They are used as an indicator organism to show the potential for disease-causing bacteria to be present in water. In other words, if coliform bacteria are present, it is presumed that a contamination pathway exists between the bacteria source and the water supply, and disease-causing bacteria may use this pathway to enter the water supply. Coliform bacteria occur frequently in private water systems, usually from contamination by surface runoff or from human or animal wastes.

Most coliform bacteria do not cause disease, but the greater their number the greater the likelihood that disease-causing bacteria may be present. Since coliforms persist in water longer than most disease-causing organisms, the absence of coliform bacteria leads to the assumption that the water supply is microbiologically safe to drink. Consuming water with coliform bacteria present may cause gastrointestinal illnesses, fever, and other flulike symptoms. Therefore, the drinking water standard requires that no coliform bacteria be present in public drinking water supplies.

Results from coliform bacteria tests are normally expressed as the number of bacteria colonies present per 100 milliliters (ml) of water. Some laboratories may simply express coliform bacteria results as "present" (P) or "absent" (A). In this case, "present" indicates only that at least one bacterium was present in each 100 ml of water. Occasionally, bacterial results are expressed as "MPN," which stands for Most Probable Number. This simply means that a statistical relationship was used to estimate the number of bacteria in your sample. Finally, bacteria results also may be reported as "TNTC," or "too numerous to count," meaning the bacterial concentration was too high to quantify.

Fecal Coliform Bacteria

Fecal coliform bacteria are a smaller group within the coliform bacteria group. Water may be tested for fecal coliform bacteria if the total coliform test is positive. Fecal coliform bacteria are specific to the intestinal tracts of warm-blooded animals and are thus a more specific test for sewage or animal waste contamination. The ratio of fecal coliform bacteria to fecal streptococcus bacteria has been used to estimate the source of bacterial contamination (see discussion below). Fecal coliform bacteria levels are expressed as the number of colonies per 100 ml of water. No fecal coliform bacteria are permitted in public drinking water supplies.

Fecal Streptococcus Bacteria

Fecal streptococcus bacteria are another smaller group within the coliform bacteria group and are especially numerous in animal waste (as opposed to human waste). The ratio of fecal coliform to fecal streptococcus bacteria is usually much higher in humans than it is in animals. As a rule of thumb, a fecal coliform to fecal streptococcus ratio greater than 4.0 is indicative of a human source of bacteria such as a septic system. A ratio less than 1.0 is indicative of an animal source of bacteria such as runoff from a feedlot. Ratios between 1.0 and 4.0 are inconclusive about the source of the bacteria. Fecal streptococcus bacteria are expressed as the number of colonies per 100 ml of water. No fecal streptococcus bacteria are permitted in drinking water.

E. Coli

An even more specific bacterial test is conducted for *E. coli* (short for *Escherichia coli).* This is a type of fecal coliform bacteria commonly found in the intestines of animals and humans. A positive *E. coli* result is a strong indication that human sewage or animal waste has contaminated the water.

Hundreds of strains of *E. coli* exist. Although most are harmless and live in the intestines of healthy humans and animals, a few can produce a powerful toxin that causes severe illness and even death. Infection often causes severe bloody diarrhea and abdominal cramps; sometimes the infection causes nonbloody diarrhea. Frequently, no fever is present. It should be noted that these symptoms are common to a variety of diseases and may be caused by sources other than contaminated drinking water.

E. coli tests are reported as the number of bacteria per 100 ml of water. The presence of any *E. coli* in a water sample is unacceptable; thus, the primary drinking water standard for *E. coli* is 0 per 100 ml of water.

Standard Plate Count (Heterotrophic Plate Count)

The Standard Plate Count (SPC) or Heterotrophic Plate Count (HPC) is a more general indicator of bacterial contamination. On some test reports, this also may be referred to as the "Total Bacteria Count." It measures all of the bacteria, including coliform and many other groups, in a water sample. The SPC is usually reported as the number of bacteria per mL of sample. This test has become rare over time due to uncertainty in the interpretation of the results. As a result, there are no drinking water standards for SPC, but if more than 500 bacteria are counted in one mL of sample, further testing for total coliform or fecal coliform bacteria is suggested.

Iron Bacteria

Iron bacteria feed on small amounts of iron in water. While they do not constitute a health threat, they are a nuisance in private water systems because they form gelatinous strands, masses, or thin films that plug pipes, toilets, and plumbing fixtures and reduce flow from wells. Their appearance can vary from orange or brown to clear. Iron bacteria can colonize an entire water system from the well itself through the plumbing, or they may be present only in parts of the plumbing system.

There are no drinking water standards for iron bacteria. Rather, their presence is normally aesthetically degrading enough to require treatment. Water testing is rarely available to determine if iron bacteria are present. Confirmation is usually based on the visual symptoms in the water, or on microscopic analysis by someone familiar with these bacteria.

Giardia *and* Cryptosporidium

Giardia lamblia and *Cryptosporidium parvum* are small microscopic animals known as protozoa. They both can live in the intestinal tracts of mammals, including humans. While there, they multiply by producing oocysts. Infected animals and humans can excrete the oocysts, which can then contaminate water sources. Once ingested, the organism emerges from the protective oocyst and infects the lining of the intestine. Both giardiasis and cryptosporidiosis cause severe diarrhea, nausea, fever, headache, vomiting, and loss of appetite. Both illnesses can be life-threatening for people with depressed immune systems.

Many private water system owners are familiar with *Giardia* and *Cryptosporidium* as a result of publicity following outbreaks of illnesses in public water supplies. Most of these outbreaks have occurred in communities that use surface water supplies (streams, rivers, lakes) where the oocysts can commonly be found. *Giardia* and *Cryptosporidium* are rarely a concern for private water systems using deeper groundwater sources, because the oocysts are efficiently filtered as water passes through soil and rock. Shallow springs or poorly constructed wells that become contaminated with surface water are the most likely to contain *Giardia* and *Cryptosporidium* oocysts. This is one reason that roadside springs are not a good alternative source of drinking water.

Both *Giardia* and *Cryptosporidium* are measured by filtering large volumes of water through a small filter and examining the filter under a microscope for oocysts. Oocysts should be totally absent from water for it to be safe to drink.

Inorganic Chemicals (IOCs)

The second category of water pollutants includes inorganic chemicals. These are usually substances of mineral origin. Salt, metals, and minerals are examples. The chemicals listed alphabetically below are the most common inorganic pollutants in Pennsylvania water supplies, or they are of the greatest health concern. Unless otherwise stated, these inorganic chemicals are usually reported in mg/L or ppm units.

Alkalinity

Alkalinity is a commonly measured water characteristic that has little meaning or importance for the typical homeowner. It is a measure of water's ability to neutralize acids. Calcium is a major component of alkalinity and of hard water. Thus, if your water has a high alkalinity, it is probably hard as well. There is no drinking water standard for alkalinity.

Arsenic (As)

Arsenic occurs in groundwater from both natural sources and human activities. In drinking water, it is odorless and tasteless. It is relatively rare in Pennsylvania water supplies, compared to those of the western United States.

In Pennsylvania, arsenic can originate naturally from certain types of rock, or it may be traced to deep-water brines produced from gas and oil well drilling or from industrial activity. Arsenic has a primary drinking water standard because it can cause skin lesions, circulatory problems, and nervous system disorders. Prolonged exposure also can cause various forms of cancer. The present arsenic drinking water standard is 10 µg/L (0.010 mg/L). A survey conducted by Penn State in 2006-07 found that arsenic exceeded 10 µg/L in 2 percent of wells in Pennsylvania. Wells with high arsenic levels are more common north of Interstate 80 owing to the natural geology of these areas.

Barium (Ba)

Like arsenic, barium occurs naturally in small concentrations in many groundwater supplies. Barium contamination is not common in private water systems in Pennsylvania, but it may occur sporadically in western and northern Pennsylvania near active and abandoned gas and oil wells.

Barium has a primary drinking water standard of 2.0 mg/L because it causes nervous and circulatory system problems, especially high blood pressure. Standard water softeners are effective in removing barium.

A study of barium levels in McKean County (a county with intensive gas well drilling) found excessive barium in about 2 percent of private wells in the county.

Chloride (Cl)

Chloride is common in Pennsylvania water supplies, but it rarely reaches levels of concern. It occurs naturally in most groundwater but may become elevated due to leaching from salt storage areas around highways or from brines produced during gas well drilling. Other possible sources of chloride are sewage effluent, animal manure, and industrial waste.

Chloride has a secondary drinking water standard of 250 mg/L because it may cause a salty taste in the water. Groundwater in Pennsylvania usually contains less than 25 mg/L of chloride.

Copper (Cu)

Copper usually originates from corrosion of copper plumbing in the home (see "Corrosivity," below). Copper has a secondary drinking water standard of 1.0 mg/L because it causes a bitter, metallic taste in water and a blue-green stain in sinks and bathtubs. It has a primary standard of 1.3 mg because of health concerns related to severe stomach cramps and intestinal illnesses. Copper can be reduced in water using the corrosion control strategies outlined below.

Corrosivity

Corrosive water is a term used to describe aggressive water that can dissolve materials with which it comes in contact. It is a problem because many homes have copper or galvanized pipes, lead solder joints, and brass plumbing fixtures. Thus, corrosive water may cause increases in copper and lead concentrations in drinking water. In rare cases, corrosive water may dissolve even PVC plastic plumbing, causing vinyl chloride contamination of the water. This generally occurs only when inferior plastic pipe that was not approved for drinking water systems has been used. Approved plastic pipe is directly stamped with "NSF" (National Sanitation Foundation) and "Drinking Water" on the side.

Symptoms of corrosive water problems include metallic taste, bluish green stains in sinks and bathtubs, and, in severe cases, small leaks in the plumbing system. Because corrosive water is not a health concern by itself, there is only a secondary or recommended standard that water be noncorrosive.

Water that is soft and acidic ($pH < 7.0$) tends to be more corrosive, but the only true measure of water corrosivity is a stability or saturation index. These indices use the water's chemical characteristics such as hardness and pH to estimate its corrosiveness. A stability index greater than about 6.5 indicates water that is probably corrosive, with higher values being increasingly corrosive. A negative saturation index value likewise indicates a corrosive water supply. The most common saturation index in use is the Langelier Saturation Index (LSI).

Past surveys of private water supplies in Pennsylvania have indicated that corrosive water is a common water-quality problem, present in over 60 percent of the groundwater wells and springs tested. It tends to be most common in northern and western Pennsylvania where more acidic groundwater is prevalent, although areas underlain by Triassic shales in southeastern Pennsylvania also produce corrosive water. It is least common in the agricultural valleys underlain by limestone where groundwater typically has a higher pH and hardness. Cistern water can be quite corrosive.

If your water test indicates that your water is corrosive, you should test your water for copper and lead. Corrosive water problems can be corrected using an acid-neutralizing filter or by replacing metal plumbing with plastic components approved by the National Sanitation Foundation (NSF).

Hardness

Hardness is a general term used to refer to the water's calcium carbonate ($CaCO_3$) content. Hardness does not pose a health threat, but it does cause aesthetic problems. It can ruin hot water heater elements, reduce soap lathering, and make laundry difficult to clean. Moderate levels of hardness are beneficial because they inhibit plumbing system corrosion. Removal of hardness using a water softener is necessary only if the water is causing aesthetic problems. Use of water softeners may result in undesirable levels of sodium in drinking water and may increase plumbing system corrosion.

Hardness may be reported in milligrams per liter (mg/L) or in a special unit called grains per gallon (gpg). One grain per gallon is equal to about 17 mg/L or parts per million (ppm). Since the level of hardness or calcium carbonate means little to consumers, a water hardness classification has been developed and appears in Table 4.3. A water hardness of about 90 to 100 mg/L provides excellent corrosion control and is usually acceptable aesthetically, but there are no drinking water standards for hardness.

Hydrogen Sulfide (H_2S)

Hydrogen sulfide (H_2S) is a noxious gas that imparts a disagreeable rotten egg odor when dissolved in water. It is a naturally occurring gas that is common in groundwater in parts of Pennsylvania. Very small concentrations of hydrogen sulfide in water are offensive to most individuals. Although hydrogen sulfide is a highly toxic gas, only under the most unusual conditions would it reach levels toxic to humans as a result of its presence in drinking water. More often, it is simply an unpleasant odor problem that can be removed using several treatment processes.

Iron (Fe)

Iron is a common natural problem in groundwater in Pennsylvania and may be worsened by mining activities. It occurs throughout Pennsylvania but is most problematic in the western region. Iron does not occur in drinking water in concentrations of health concern to humans. The secondary drinking water standard for iron is 0.3 mg/L because it causes a metallic taste and orange-brown stains that make water unsuitable for drinking and clothes washing.

Lead (Pb)

If lead is detected in your drinking water, it probably originated from corrosion of your plumbing system. Lead was a common component of solders used in plumbing systems until it was banned in 1991. In homes built in the early 1900s, lead pipe also may be present. Thus, if your home was built before 1991 and has a metal plumbing system, it is likely that some lead is present. If your water supply is corrosive (see discussion above), then any lead present in the plumbing system may be dissolved into your drinking water. Lead concentrations are usually highest in the first water out of the tap (known as "first-draw" water), since this water has been in contact with the plumbing for a longer time. Lead concentrations typically decrease as water is flushed through the plumbing system.

A survey in 1989 found that about 20 percent of the private water supplies in Pennsylvania contained lead concentrations above the MCL of 0.015 mg/L (15 µg/L). In 1991 the federal government took steps to limit lead in water plumbing systems. As a result, a recent survey of private water systems in Pennsylvania found that lead contamination had declined from 20 percent in 1989 to 12 percent in 2007 (Swistock et al. 2009).

Lead levels can seriously threaten drinking water safety. Lead is colorless, odorless, and tasteless. Long-term exposure to lead concentrations in excess of the drinking water standard has been linked to many health effects in adults, including cancer, stroke, and high blood pressure. At even greater risk are the fetus and infants up to four years of age, whose rapidly growing bodies absorb lead more quickly and efficiently. Lead can cause premature birth, reduced birth weight, seizures, behavioral disorders, brain damage, and lowered IQ in children. The U.S. Environmental Protection Agency considers lead to be the most serious environmental health hazard for children in the United States.

More than 90 percent of lead problems in drinking water can be traced to corrosive water and lead impurities in the plumbing system. It should be noted, however, that in rare cases the source of lead in drinking water might be groundwater pollution rather than corrosion of the plumbing system. Such pollution may be the result of industrial or landfill contamination of an aquifer. The source of the lead usually can be determined by comparing water test results from a first-draw sample versus a sample collected after the water runs for several minutes. If the lead concentration is high in both samples, then the source of the lead is likely from groundwater contamination.

Manganese (Mn)

Like iron, manganese is a naturally occurring metal that may be worsened by mining activities. Manganese concentrations normally found in drinking water do not constitute a health hazard; however, even small amounts of manganese may impart objectionable tastes or blackish stains to water. For this reason, manganese has a recommended drinking water standard of 0.05 mg/L.

Table 4.3. Water hardness classifications.

Classification	Hardness (mg/L or ppm)	Hardness (gpg)
Soft	Less than 17	Less than 1.0
Slightly hard	17 to 60	1.0 to 3.5
Moderately hard	60 to 120	3.5 to 7.0
Hard	120 to 180	7.0 to 10.5
Very hard	More than 180	More than 10.5

Nitrate (NO_3) or Nitrate Nitrogen (NO_3-N)

Nitrate in drinking water usually originates from fertilizers or from animal or human wastes. Nitrate concentrations in water tend to be highest in areas of intensive agriculture or where there is a high density of septic systems. In Pennsylvania, nitrate exceeds 10 mg/L in about 2 percent of all private water systems, but in the southeastern and southcentral counties where agriculture is most prevalent, it exceeds 5 percent.

Nitrate has a primary drinking water standard that was established to protect the most sensitive individuals in the population (infants under 6 months of age and a small component of the adult population with abnormal stomach enzymes). These segments of the population are prone to methemoglobinemia (blue baby disease) when consuming water with high nitrates. The need for a nitrate MCL has been questioned lately because blue-baby disease occurs very rarely in the United States.

Nitrate may be reported on your water test report as either nitrate (NO_3) or nitrate-nitrogen (NO_3-N). Look carefully at your report to determine which form of nitrate is being reported. The primary drinking water standard or MCL is 10 mg/L as nitrate-nitrogen (NO_3-N), but it is 45 mg/L as nitrate (NO_3).

pH

The pH of water is a measure of how acidic or basic the water is. It is measured on the pH scale (from 0 to 14) in pH units. If the pH of water is less than 7.0, it is acidic, and if it is greater than 7.0, it is basic. Water with a pH of exactly 7.0 is considered neutral. If pH values deviate very far from neutral, other water-quality problems may be indicated. These would include the presence of toxic metals such as lead (at low pH) and high salt contents (at high pH).

It is recommended that the pH of your water be between 6.5 and 8.5 to minimize other potential water-quality problems. Acidic water with a pH less than 6.5 is much more common in Pennsylvania (occurring in 18 percent of private wells) than high-pH water (occurring in only 2 percent of private wells), especially in the northern and western regions of the state. In general, pH is an indicator of other potential water-quality problems and is very rarely a problem by itself.

Sulfate (SO_4)

Sulfates normally are present at some level in all private water systems. Sulfates occur naturally as a result of leaching from sulfur deposits in the earth, or from the breakdown of sulfate minerals in the environment, such as the weathering of iron pyrite ($FeSO_4$). Private water systems with excessive sulfate in Pennsylvania are generally confined to the western portions or other coal-mining regions. Even in these areas, surveys indicate that less than 10 percent of the water supplies have excessive sulfate. Other less common sources are industrial waste, sewage effluent, and gas wells.

Sulfate has a secondary drinking water standard of 250 mg/L because it may impart a bitter taste to the water at this level. A proposal also exists to make sulfate a primary contaminant with an MCL of 500 mg/L, because it may have a laxative effect and cause other gastrointestinal upsets above this concentration.

Total Dissolved Solids (TDS)

The total amount of substances dissolved in water is referred to as the total dissolved solids (TDS) content of water. Waters high in TDS often contain objectionable levels of dissolved salts such as sodium chloride. Thus, high TDS may indicate the presence of other water-quality problems. The recommended drinking water standard of 500 mg/L for TDS exists because high-quality waters generally have lower TDS levels.

Turbidity

Drinking water should be sparkling clear for health and aesthetic reasons. Turbidity refers to fine particles of clay, silt, sand, organic matter, or other material that might reduce the clarity of water. Turbidity makes water unappealing to drink because of its muddy appearance. Particles also might act to shield disease-causing bacteria from chlorine or ultraviolet light treatment and provide nutrients for bacteria and viruses to flourish.

Turbidity usually indicates direct pollution from surface runoff often during or shortly after heavy rainfall. Turbidity might increase in wells because of borehole cave-ins; it also might increase when water levels in the well are low such as during a drought, because the submersible pump may disturb sediments near the bottom of the well.

Turbidity is usually measured in a special unit known as an NTU, or Nephelometric Turbidity Unit. Drinking water should not exceed 1 NTU, for both health and aesthetic reasons. Water with even 10 NTUs of turbidity is essentially clear to the naked eye; thus, testing is required. Water with more than 1 NTU of turbidity makes disinfection to kill bacteria difficult and is the primary reason for the 1 NTU standard.

Organic Chemicals

Organic chemicals are a large group of over 100 mostly human-made chemicals. They can occur in drinking water sources from industrial activity, landfills, gas stations, pesticide use, or air deposition. Organic chemicals vary in their ability to pollute groundwater and their toxicity. Many organic chemicals are carcinogenic (cancer causing), so they often have very low drinking water standards, usually measured in µg/L. Remember that µg/L are the same as ppb (parts per billion).

Generally speaking, organic chemicals can be grouped into two major categories: volatile organic chemicals (VOCs) and nonvolatile or synthetic organic chemicals (SOCs). The discussion below introduces these general groups of organic chemicals and describes in detail the most common examples in each group. Specific drinking water standards for all organic chemicals are given in Table 4.2.

Volatile Organic Chemicals (VOCs)

VOCs are human-made compounds that volatilize from water into air. They present a health risk not only from drinking contaminated water, but also from inhaling VOCs that escape from the water as it is used during showering or other home uses. VOCs also are absorbed directly through the skin during bathing and showering. They are commonly used as solvents, fuels, paints, or degreasers. Virtually all VOCs produce an odor in water, although it may not be obvious before the drinking water standard is exceeded. Nearly all VOCs have primary drinking water standards, because they are carcinogenic (cancer-causing) or cause damage to the liver, kidneys, nervous system, or circulatory system.

VOCs are not common in private water systems in Pennsylvania, but they are becoming a more important concern as industrial activities, landfills, gas stations, and other sources of these pollutants encroach on rural areas. The U.S. Geological Survey conducted a survey of 118 wells in southern and eastern Pennsylvania. The survey analyzed well water for 60 different VOCs and detected at least one VOC in 27 percent of the samples. (Although the VOCs were commonly detected, none of the samples exceeded drinking water standards.) VOC contamination of wells was much more common in urban areas than agricultural areas (Zogorski et al. 2006).

Dozens of VOCs are regulated in public water supplies, but the most common are described below. Consult Table 4.2 for a complete list of drinking water standards for all regulated VOCs.

Benzene

Benzene is a clear liquid that is used primarily as an industrial solvent and chemical intermediate. It is lighter than water, migrates easily in groundwater, and is slow to decay. It is also present as a gasoline additive. Because it is a known human carcinogen, benzene has a primary drinking water standard of 0.005 mg/L (5 μg/L).

Carbon Tetrachloride

Carbon tetrachloride is a colorless liquid that is heavier than water but migrates easily in groundwater. It has been used mostly for the production of chlorofluorocarbons and in the dry-cleaning industry. Carbon tetrachloride has a primary drinking water standard of 0.005 mg/L (5 μg/L) because it is a probable human carcinogen with other acute effects on the gastrointestinal and nervous systems.

Chloroform

Chloroform is a colorless liquid that is used primarily to make other chemicals. It also can be found in small amounts when chlorine is added to water. Chloroform travels easily in groundwater and does not easily degrade. Chloroform is believed to be a carcinogen. It has been one of the most commonly reported organic chemicals in Pennsylvania groundwater.

Chloroform is one of a group of organics known as trihalomethanes or THMs. No specific drinking water standard exists for chloroform, but the primary standard for THMs is 0.08 mg/L (80 μg/L).

MTBE (Methyl Tert-Butyl Ether)

MTBE is the most common organic chemical found in Pennsylvania groundwater. It has been used extensively as a gasoline additive in some parts of the United States to reduce air pollution emissions from automobiles. It smells like turpentine and can often be detected in water at low concentrations. Most MTBE originates from gasoline spills or leaking underground storage tanks. It is more water soluble than other components of gasoline, so it contaminates groundwater more easily. Once in groundwater, MTBE is slow to decay. MTBE is a possible human carcinogen, but little information is available on other health effects. Pennsylvania presently has no drinking water standard, but numerous other states have set standards in the 0.02 to 0.2 mg/L range (20 to 200 μg/L). More information on MTBE is available online at www.epa.gov/safewater/contaminants/unregulated mtbe.html. Other online resources for MTBE can be found at www.epa.gov/swerust1/mtbe/othrlink.htm#/.

Tetrachloroethylene (PCE) and Trichloroethylene (TCE)

Tetrachloroethylene (commonly known as PCE) and trichloroethylene (commonly known as TCE) are similar chemicals that have been found in Pennsylvania around industrial sites and landfills. Most of the groundwater contamination from these chemicals has occurred because of improper disposal of industrial wastes. Both chemicals are used as industrial solvents for metal degreasing, but PCE is used primarily in the dry-cleaning industry. Both are heavier than water and move freely through soil and groundwater, but TCE is much more water soluble than PCE. PCE is a possible carcinogen that causes liver, kidney, and nervous system damage. TCE is a probable carcinogen that also causes acute effects to the liver, kidneys, and central nervous system. Both PCE and TCE have primary drinking water standards of 0.005 mg/L (5 μg/L).

Xylenes

Xylenes are a component of gasoline. They also are used in the manufacturing of some chemicals and therefore appear commonly in industrial wastes. Xylenes cause liver, kidney, and nervous system damage. Xylenes biodegrade and move slowly in groundwater. Xylene has been reported in much higher concentrations than most other VOCs in Pennsylvania, but the drinking water standard for xylenes is also much higher (10 mg/L or 10,000 µg/L).

Nonvolatile or Synthetic Organic Chemicals (SOCs)

Nonvolatile organic chemicals are also known as synthetic organic chemicals, or SOCs. Nearly all SOCs are pesticides, with a few notable exceptions (PCBs and dioxin). They differ from VOCs because they do not escape readily into the air from water.

Dozens of pesticides, including herbicides, insecticides, and fungicides, are used throughout Pennsylvania on crops, golf courses, and lawns. The risk to private water supplies from pesticide applications depends on many factors, including the amount, mobility, and toxicity of the pesticide, the proximity of the application to the water supply, and the depth and construction of the water source.

Pesticides are not common in private water supplies, but they are often detected in agricultural areas of the state. An unpublished 1993 study by Penn State scientists found detectable residues of at least one pesticide in 27 percent of the rural wells surveyed in corn-producing regions of Pennsylvania. (Although the pesticides were commonly detected, none of these wells contained a concentration above the drinking water standard.) A more recent 2006-07 Penn State study found unsafe levels of triazine pesticides (atrazine, simizine, etc.) in just 3 of 701 wells statewide (Swistock et al. 2009). Pesticide concentrations are generally higher in wells located in limestone, which includes most of the prime agricultural regions of Pennsylvania.

Detailed descriptions are given below for some of the pesticides most often found in Pennsylvania groundwater. For more information on these and other less common pesticides visit www.epa.gov/pesticides/ or www.cas.psu.edu/docs/casdept/pested/index.html. A publication (NRAES-34), *Pesticides and Groundwater*, can be ordered from NRAES, www.nraes.org.

Atrazine

Atrazine is the most commonly used herbicide in Pennsylvania. It is applied to nearly 90 percent of the state's corn crop. It is water soluble, moves easily into groundwater and surface water after application, and is by far the most common pesticide reported in private water supplies in Pennsylvania. Because it is classified as a possible human carcinogen that also damages the liver, kidney, and heart, atrazine has a primary drinking water standard of 0.003 mg/L (3 µg/L).

2,4-Dichlorophenoxyacetic Acid (2,4-D)

2,4-D is widely used to kill broad-leaved weeds in farm fields and pastures and on lawns and golf courses. It also is used to kill algae and aquatic plants in ponds and lakes. 2,4-D damages the liver, circulatory, and nervous systems. Like atrazine, it is one of the most commonly used pesticides in Pennsylvania and one of those most often found in groundwater in the state's agricultural areas. 2,4-D has a primary drinking water standard of 0.07 mg/L (70 µg/L).

Chlorpyrifos

Chlorpyrifos, also known as Dursban, has been one of the most commonly used insecticides on corn crops in Pennsylvania. It has also been used to control pests on cattle, and it was widely used around the home for control of cockroaches, fleas, and termites. Chlorpyrifos does not mix well with water and sticks tightly to soil particles. It was detected in trace amounts in a small percentage of private water systems in a 1993 study. Chlorpyrifos is presently considered a possible human carcinogen. No drinking water standard exists for chlorpyrifos, but the U.S. Environmental Protection Agency (EPA) recommends that children not drink water containing levels greater than 0.03 mg/L. The use of chlorpyrifos was severely restricted as of December 31, 2001 The EPA announced a ban on the production of chlorpyrifos, starting in June 2000.

Glyphosate

Glyphosate is one of the most widely used pesticides in the United States. It is a herbicide used mostly to control broad-leaved weeds and grasses in pastures, corn, soybeans, and lawns. It is a component of the often-used herbicide Roundup®. Glyphosate has a primary drinking water standard of 0.7 mg/L (700 µg/L) because it causes kidney damage and reproductive effects after long-term exposure. Glyphosate is strongly adsorbed to soil and does not readily move to or in groundwater.

Metolachlor

Metolachlor is the second most commonly used herbicide on corn in Pennsylvania. It is slightly less mobile than atrazine but still moves easily through soil to groundwater. A 1993 survey of private water systems in Pennsylvania found metolachlor to be the third most commonly detected pesticide in the state. There are no reported short-term effects from exposure to metolachlor in water, but it is listed as a possible carcinogen with prolonged exposure. No drinking water standard exists, but further testing is being done by the EPA. In the interim, the EPA has issued a health advisory for metolachlor of 0.07 mg/L (70 µg/L).

Simazine

Simazine is commonly used to control broad-leaved and grassy weeds on crops, orchards, and Christmas tree farms. It has a primary drinking water standard of 0.004 mg/L (4 µg/L) because it is a probable carcinogen that also can damage the testes, kidneys, liver, and thyroid after long exposure. Simazine travels easily through soils to groundwater and persists in groundwater for long periods of time.

Dioxin (2,3,7,8-TCDD)

Dioxin (also known as 2,3,7,8-Tetrachlorodibenzo-1-,4-dioxin or 2,3,7,8-TCDD) is a contaminant formed in the production of some chlorinated organic compounds, including a few herbicides. It may also be formed when some chlorinated organic chemicals are burned. Dioxin has been linked to a variety of health effects, including liver damage, reproductive effects, birth defects, and cancer. Most dioxin in water comes from improper disposal of industrial wastes. It is not very water soluble, and most dioxin is found adhering to sediment or organic particles. It does not move easily into groundwater because it is usually trapped in soil. It has the lowest drinking water standard of any regulated substance (0.00000003 mg/L or 0.00003 µg/L).

Polychlorinated Biphenyls (PCBs)

PCBs are a group of manufactured organic chemicals that are odorless and tasteless in water, and pervasive and persistant in the environment. They have been used widely as insulating materials, coolants, and lubricants in electrical equipment. The manufacture of PCBs stopped in the United States in 1977 because of health effects, but products containing PCBs are still prevalent. Most PCBs in groundwater originate from improper waste disposal. In water, a small amount of PCBs may remain dissolved, but a larger amount sticks to organic particles and sediments. PCBs have been shown to cause numerous health effects, including liver, kidney, and nervous system damage. They are also considered probable carcinogens. As a result, a primary drinking water standard of 0.0005 mg/L (0.5 µg/L) exists for PCBs.

Radiological Pollutants

Radioactivity usually occurs in water from radium, uranium, or radon. These materials emit radioactivity as alpha, beta, or gamma radiation. Each form of radiation affects the human body differently, yet all can lead to cancer. Radioactivity in water is normally measured in picocuries per liter (pCi/L). Several drinking water standards exist for radioactivity (see Table 4.2). Radon is likely to be the most common radiological problem in Pennsylvania.

Radon

Radon is a naturally occurring radioactive gas formed underground by the decay of uranium or radium deposits. Radon can enter groundwater as it escapes from surrounding rocks. The gas is then released during household uses of the water such as showering, dishwashing, or laundering. Radon has been shown to cause lung cancer upon inhalation, but ingestion of radon in water is not thought to be a major health concern. Thus, the most serious threat from radon in water is the inhalation of escaping gas during showering or bathing. For this reason, the U.S. EPA has proposed drinking water standards for radon in water ranging from 300 to 4,000 pCi/L.

Recent surveys by the Pennsylvania Department of Environmental Protection and the U.S. Geological Survey indicate that over 60 percent of the private water supplies in Pennsylvania contain more than 300 pCi/L of radon; about 20 percent exceed 4,000 pCi/L of radon. The problem is most severe in southeastern counties, but it is present throughout the state.

Chapter 5—Solving Water-Quality Problems

It is not uncommon for drinking water supplies to become contaminated by either natural or human-made processes. However, private water system owners are especially vulnerable to drinking water from unsafe sources, since testing is not required and most rural homeowners do not know what they should be testing their water for on a regular basis. Homeowners relying on private water supplies should take the time to learn what water tests are needed, how to take the sample, where to go to have the sample analyzed, and how to interpret the results. Testing should be done on a regular basis and reports kept in a secure location with other important documents (see Chapter 4 for details).

Once testing has been completed by a state-certified laboratory and the results accurately interpreted, you can make the necessary decisions regarding how to solve water-quality problems. Immediately identifying and contacting a water treatment vendor is a common mistake that many people make after they find out they have a water-quality problem. Water treatment is just one of several options that a homeowner has when water-quality problems exist in a private water system.

WHAT OPTIONS ARE AVAILABLE?

Once you know what contaminants are found in your drinking water and you understand how serious each is for the health of your family, you can make informed decisions regarding how to eliminate each from your water supply. This decision can best be made after you explore the following options:

Pollution control—Identify the source of pollution and eliminate it or divert it away from your drinking water supply. Many times a contamination problem may be caused by a pollution source existing near your water supply. Check the surrounding area and inspect your water system to ensure that the problem isn't something that can be removed with little effort.

Water system maintenance—Water-quality problems often arise because of water system neglect. Sometimes a little maintenance or an inspection by a qualified professional can provide an easy fix for a water-quality problem.

Water treatment—Almost any water-quality problem can be eliminated through the use of water treatment equipment. However, treatment equipment can be very expensive, and it is important that you be knowledgeable about what equipment is needed before seeking assistance from a treatment vendor. More information about water treatment can be found throughout this chapter.

New system development—After looking at all of the options available to you, it may be best to develop a new source of water. If it is possible to find a higher-quality water supply by drilling a new well, constructing a rainwater cistern, or hooking onto a nearby public water system, one of these may be a better alternative than buying several different types of treatment equipment, all of which have their own maintenance requirements.

The remainder of this chapter focuses on water treatment options for common water-quality issues. Water treatment is complex, requiring an understanding of basic treatment processes. However, do not underestimate the role of maintenance, controlling pollution sources, and new water source development in solving water-quality problems. Those are, generally speaking, better options if they are available.

HOME WATER TREATMENT IN PERSPECTIVE

Drinking water treatment equipment is gradually becoming commonplace in many homes and offices. A 2006-07 study found that about half the homes in Pennsylvania with a private water supply used some type of water treatment (Swistock et al. 2009). Ion exchange units, carbon filters, and countertop distillation units are among the systems used. Consumers can choose from two basic types of treatment: point of entry (POE) or point of use (POU). POE equipment is placed so that all water entering the structure is treated. POU equipment is strategically placed only where treated water is desired, such as the kitchen sink.

The rise in popularity of water treatment devices is evidenced by the growth in the water treatment industry, which has become a major industry in the United States. In fact, current manufacturers design, produce, and market a wide variety of treatment devices that promise to provide cleaner, purer, or safer water. While many water treatment manufacturers are reputable companies concerned about consumer welfare, some manufacturers prey on the buyer's ignorance or apprehension and use misleading advertising techniques to sell their products.

Home water treatment can be confusing and expensive. This section is provided to help answer some common questions about when and how to purchase treatment equipment.

MISCONCEPTIONS ABOUT HOME WATER TREATMENT

Misconceptions about home water treatment arise out of a combination of false advertising, consumer myths, and misinformation. They are perpetuated by nonuniform testing standards and a lack of product certification requirements.

Let's take a look at common advertising and selling strategies used by some POE-POU treatment manufacturers. First, companies advertise with misleading or even false statements such as "a device that is your only solution to purer water . . . a device that produces water like God made in the beginning . . . water that will make your hair more silky and manageable . . . healthier water." Sometimes generalized statements are made about all units when they apply only to a particular model. These strategies mislead buyers into believing that a device is the answer to *all* their water-quality problems.

Another common selling technique for water treatment equipment is the use of door-to-door "water specialists." These salespeople run a "free" test on your water and use colorful charts to show how their devices remove the contaminants discovered in your water. They tell you about phony national surveys, special trips you can win, and the contaminated, detrimental condition of the water flowing from your very own kitchen sink. Their presentation usually ends with a final sales pitch to coerce you into "making a decision today that will keep you healthy for the future."

Consumers plagued by exaggerated health fears or misinformation are easy prey for such hard-sell techniques. The environmental and health information readily available to the public in newspapers, magazines, and documentaries often enlarges the risk of certain chemicals and puts doubt in consumers' minds about just how safe their water is. If a test reveals the presence of a particular contaminant, many homeowners view water treatment as a quick fix. Then, without knowing which devices are intended for which problems, they seek help from a "professional" who sells them the wrong equipment. To further complicate the situation, a buyer often is not made aware of equipment maintenance requirements or warranties. As a result, the device fails to remove contaminants and, in some cases, may actually introduce other contaminants into the water supply.

Unfortunately, another common misconception that permeates the POU-POE treatment industry is that water treatment equipment is the only solution for water-quality problems. As mentioned earlier, this is not always the case and homeowners should research all solutions before settling on water treatment.

What Can You Do?

Today, almost any water-quality problem (both nuisance and health based) can be fixed by purchasing the appropriate equipment. However, homeowners with private water systems are often uninformed about water treatment processes and equipment, making them susceptible to unscrupulous businesses selling treatment equipment. The following tips will assist you in considering the purchase of water treatment equipment.

Understand the Water-Quality Problem

If you suspect you have a problem with your water, make sure to have it tested by an *unbiased state-certified water-testing laboratory*. A list of state-certified water-testing laboratories is available from your local Pennsylvania Department of Environmental Protection office, online at water.cas.psu.edu, or at your county Penn State Cooperative Extension office. If test results from a certified laboratory show that your drinking water failed a primary, health-based drinking water standard, such as that for bacteria or lead, you should take action to correct the problem to protect your health and that of your family. Other water tests may indicate a problem from a secondary pollutant such as iron or manganese. In this case your health is not at risk, but you may choose to install water treatment equipment to reduce stains, tastes, or odors these pollutants can cause.

Consult Unbiased Water-Quality Experts

After receiving your test results from the certified water-testing laboratory, it is a good idea to go over the results with an unbiased water-quality expert. Unbiased experts may be available from the water-testing laboratory or from your county extension office. They can help you interpret the test results and provide advice on options for fixing any water-quality problem.

Match Treatment to Problem

Once you have decided that treatment is the best solution to your problem, learn about each of the basic water treatment processes and the pollutants they remove. Become an educated consumer and know which treatment devices will solve your problem before you approach treatment vendors. Table 5.1 provides information on the most common water treatment processes.

Research Treatment Companies

Always seek reputable water treatment companies that will provide you with local customer references. Research the company's history and look for those that have been established in the area for several years. Fly-by-night operations are common in the water treatment business, and you want to avoid them.

Beware of Hard-Sell Techniques

As discussed earlier, some water treatment vendors may use colorful home water tests or other methods to scare or pressure homeowners into buying water treatment equipment on the spot. Be cautious of companies using this strategy. Never make quick decisions. Confirm home water test results through an independent lab. Take your time and consult with other experts and other treatment vendors to get second and third opinions.

Ask About Maintenance Requirements

Purchasing water treatment equipment can be expensive and can be complicated by regular maintenance required for the equipment. Make sure you fully understand the maintenance requirements of all equipment before you buy. All water treatment equipment requires routine maintenance. Sometimes this maintenance is simple, such as replacing a faucet carbon filter or ultraviolet light bulb. In other cases, maintenance is more involved, such as regenerating oxidizing filters or replacing membranes in reverse osmosis units. It is best to understand the details of treatment equipment maintenance before you buy. Determine what maintenance will be done by the treatment company and what your responsibility will be.

Table 5.1. A summary of common water treatment processes used in Pennsylvania.

Treatment method	Primary uses	Type of unit[1]	Notes
Acid neutralization	Corrosive water, copper, lead, pinhole leaks in plumbing	POE	Uses limestone chips or soda ash to increase water pH and hardness to prevent corrosion. Never combine with softener.
Activated alumina	Arsenic, fluoride	POE or POU	Water pH must be less than 8.5. Pretreatment with oxidation may be necessary to achieve good arsenic removal.
Aeration	Hydrogen sulfide, methane, volatile organics, radon	POE	Expensive and susceptible to clogging by other pollutants, but very effective when multiple gases are present. Requires disinfection treatment.
Anion exchange	Sulfate, nitrate, arsenic	POE or POU	Increases chloride concentration in treated water. May make water more corrosive.
Carbon filter	Chlorine, pesticides, herbicides, radon, miscellaneous tastes and odors, human-made volatile organics, limited removal of hydrogen sulfide odor	POE or POU	Disinfection should be used on water supplies with bacterial contamination because bacteria can multiply in filter. Carbon must be periodically replaced when exhausted.
Chlorination	Bacteria, hydrogen sulfide, iron	POE	Water must be clear for chlorine to work. Must also provide a tank for storage and contact time. pH adjustment may be necessary.
Distillation	Removes everything *except* volatile organics, pesticides, herbicides	POU	Produces small amounts of bland-tasting water. Space needed to store treated water.
Oxidizing filters	Iron, manganese, hydrogen sulfide	POE	Periodic addition of chemicals is necessary along with backwashing. Good option when two or all three pollutants are present.
Ozone	Bacteria, metals, odors, tastes	POE	Expensive to purchase and operate but very effective at removing multiple pollutants.
Reverse osmosis	Removes any dissolved pollutants from water	POU	Produces small amounts of water and produces some waste water. Does not remove most organic pollutants or bacteria.
Sediment filters	Soil, sand, other particles. Certain types can also be used to remove *Giardia* cysts	POU or POE	Must be routinely changed (POU) or backwashed (POE) to maintain water flow.
Softeners	Removes hardness (scale) along with limited amounts of dissolved iron	POE	Causes increase in water sodium level. Use potassium salt or only soften hot water if on a low-sodium diet. Water may become more corrosive after softening.
Ultraviolet light	Bacterial disinfection	POE	Water must be free of sediment to kill bacteria effectively. Bulb must be changed annually.

[1] POU = point-of-use treatment device used to treat the water at one faucet or tap where the water is used. POE = point-of-entry treatment device used to treat all of the water as it enters the home.

Look for NSF and WQA Certifications

Several independent associations provide testing of water treatment equipment to determine its effectiveness. Two such organizations are the National Sanitation Foundation (NSF) and the Water Quality Association (WQA). Ask water treatment vendors to provide written proof of these certifications for their equipment. Note that EPA certification does not ensure that equipment will remove certain pollutants.

Costs of Water Treatment Equipment

Costs of water treatment equipment vary considerably depending on the type of unit, size, pretreatment requirements, and installation. Small faucet or pour-through carbon or activated alumina filters often cost less than $20. Other countertop or faucet point-of-use (POU) devices such as reverse osmosis and distillation units can cost $300 to $2,000, depending on the amount of water they produce per day. Most larger, whole-house point-of-entry (POE) filters, such as softeners, anion exchange units, carbon filters, oxidizing filters, and acid neutralizing filters, cost $500 to $1,500. Ultraviolet light disinfection systems can range from $400 for a basic unit to more than $1,000 for one with a light intensity sensor, sleeve cleaner, and automatic shut-off. Aeration and ozonation are usually the most expensive systems, costing several thousand dollars. According to the 2006-07 Penn State survey, homeowners reported spending on average about $1,300 on water treatment equipment and installation (not including upkeep) (Swistock et al. 2009).

Final Thoughts...

Approach any water treatment purchase carefully after receiving a water test report from an unbiased source. Get multiple estimates from reputable companies. Once you have made a decision, get everything in writing including a detailed warranty and maintenance agreement.

The following section gives a brief explanation of common water treatment devices and the contaminants they remove. Consult your county extension office or the Pennsylvania Master Well Owner Network at mwon.cas.psu.edu. Or e-mail mwon@psu.edu for more assistance.

COMMON WATER TREATMENT METHODS

Acid Neutralizing Filters

Acid-neutralizing filters are simple water treatment units intended to increase pH and add calcium, thereby decreasing corrosivity. They consist of a tank filled with calcium carbonate (limestone) chips, marble chips, magnesium oxide, or other alkaline material. Since corrosion affects the entire plumbing system, these treatment devices are installed where the water enters the home to treat all of the household water (point of entry, or POE). They are usually installed after the pressure tank. Raw water flows through the tank and as it contacts the media, its pH is increased and corrosivity decreased. Note: This process increases the water's hardness, but this is necessary for proper corrosion control. Also, the resistance of the neutralizing material may lower water pressure.

Frequent maintenance is required for neutralizing filters. The tank must be routinely refilled with neutralizing material as it is dissolved. The rate of refilling can range from weeks to months depending on the raw water corrosivity, water use, and the type of neutralizing material. Backwashing is recommended to remove trapped particles and oxidized metals unless a sediment filter is installed ahead of the unit.

Aeration Units

Home aeration units expose water to air so that contaminants like volatile organic chemicals and dissolved gases, such as radon, hydrogen sulfide, and methane, can be removed. These systems treat all of the water entering the home and range from simple systems, with spray aerators enclosed in a tank, to packed tower aerators, which collect and release the accumulated gas. Home aeration units are expensive, usually starting at around $3,000. This figure doesn't include installation or maintenance costs.

A spray aeration unit sprays contaminated water into the tank using a spray nozzle. The increased surface area of the sprayed water droplets causes the pollutant to volatilize while the air blower carries the contaminated air to a vent outside the home. To keep a supply of treated water, at least a 100-gallon holding tank usually must be used.

Packed-column aeration units allow water to move in a thin film over inert packing material in a column. The air blower forces contaminated air back through the column to an outdoor vent.

In a shallow-tray aeration unit water is sprayed into the tray and then flows over the tray as air is sprayed up through tiny holes in the tray bottom. The treated water collects in the tank bottom and is pumped to the water pressure tank. Advantages of this type of aeration include no fouling problems in tray holes, and the small size of the unit. However, this system requires larger amounts of air compared to the others.

Aeration systems are sometimes used to remove volatile organic compounds from industrial or fuel spills, but they are most often chosen for the removal of radon, hydrogen sulfide, or methane gases.

With new technological advancements in home aeration, the EPA has listed aeration as the best available technology for removing radon from water. Aeration units can have radon removal efficiencies of up to 99.9 percent. They are also ideal for high waterborne radon levels. Be aware, however, that to date neither the National Sanitation Foundation or the Water Quality Association has tested these units.

In comparison to chemical methods that might be used for hydrogen sulfide gas treatment, aeration may be advantageous because it does not add chemicals to the water. Maintenance costs are low for aeration units, but the initial purchase costs are often higher than other treatment options. Aeration is not usually efficient enough to remove all of the offensive odor at high hydrogen sulfide concentrations; thus, it is normally not used when hydrogen sulfide concentrations exceed about 2 mg/L. Sometimes aeration forms sulfur particles that must be filtered from the water. Disinfection of aerated water is recommended.

If aeration is used for methane removal, the aeration units should be placed if possible in a separate building where the methane is vented from the water before entering your home. In some cases, this is done by pumping the well into a buried cistern or storage tank that can be vented or aerated outside the home. Installing aeration devices in your basement with a vent leading outside is a less desirable alternative. Aerated water requires disinfection before use.

Ion Exchange (IE)

IE for anions such as nitrate, sulfate, and arsenic is similar to the process used in conventional water softeners, only anions (negatively charged ions) are being exchanged instead of cations (positively charged ions). These systems can be used to treat all the water entering the home, or they can be set up to remove contaminants from water used only for drinking and cooking.

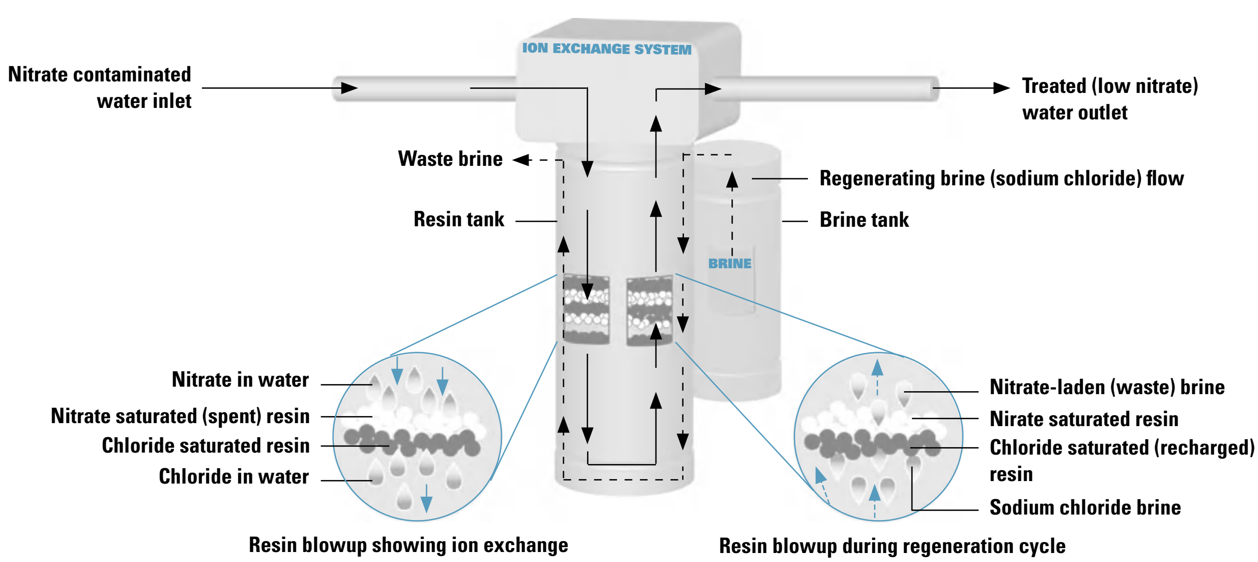
These units consist of a tank filled with resin beads coated in chloride. As water passes through the unit, the anions (such as nitrate, sulfate, or arsenic) adsorb to the resin, and chloride leaves with the treated water.

For nitrate removal, the resin exchanges chloride ions for nitrate and sulfate ions in the water. After treating many gallons of water, the resin “runs out” of chloride. Regenerating the resin with a concentrated solution of sodium chloride (you can use bicarbonate instead of chloride) recharges it for further treatment. Figure 5.1 shows how the anion exchange process works.

Anion exchange does have drawbacks. Because the resin prefers sulfate exchange, sulfates are exchanged before nitrates, thus, high sulfate water reduces system effectiveness. When the resin becomes saturated, it releases nitrates, resulting in an increased nitrate concentration in the “treated” water. Also, nitrate ion exchange can make the water corrosive. Neutralizing the water after it leaves the unit reduces this effect. Finally, ion exchange can be expensive and requires maintenance. Since the backwash brine is high in nitrates, care must be given to its disposal.

IE for arsenic removal works much like the nitrate system. Arsenic in the water is removed and chloride is added to the water in its place. Sulfate, total

Figure 5.1. Anion exchange unit showing nitrate removal and regeneration.



dissolved solids, selenium, fluoride, and nitrate all compete with arsenic and can reduce the efficiency of arsenic removal. Suspended solids and precipitated iron can also clog the IE unit and may require pretreatment. IE is usually a whole house POE device that treats all of the water entering the home. IE resins can be regenerated with much less dangerous chemicals than the activated alumina filter, but IE may increase water corrosivity by removing alkalinity. Neutralization may be required as an additional treatment to reduce corrosivity.

Cation Exchange (Water Softening)

Once water hardness is known, you have two options. You can live with the hardness level, recognizing that levels below 7.0 grains per gallon (gpg) will probably not cause major scaling and soap film, or treat the water to reduce the calcium and magnesium present. A water softener, which is a cation exchange unit, will effectively accomplish the latter option.

Because water-softening devices have long been available in the water treatment industry, the technology is highly developed and in most cases works well to reduce the hardness level. Water softening is a chemical process that filters the water through an exchange media known as resin or zeolite. Typically, the resin is a synthetic or natural, sandlike material coated with positively charged sodium ions. As the calcium and magnesium dissolves into positively charged ions, an ion exchange environment is created. The water flows through the unit while the resin releases its sodium ions and readily trades them for the calcium and magnesium ions. The water flowing out of the device is now considered soft.

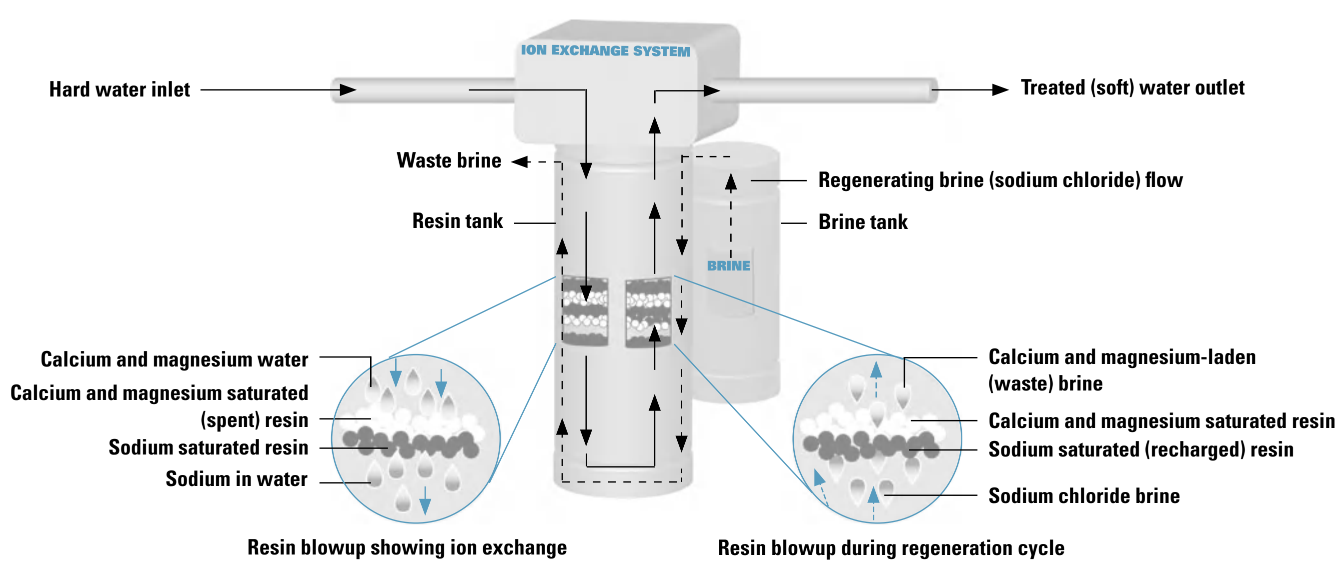
Regeneration

Clearly the resin is not an inexhaustible exchange site. When all the sodium exchange sites are replaced with hardness minerals, the resin is spent and can no longer soften water. At this point, the water softener needs to be run on an alternate cycle called regeneration. During this cycle, resin is backwashed with a salt solution. The brine is reverse flushed through the system, taking with it the calcium and magnesium ions that had been adsorbed on the resin. Once backwashing is complete, the softener can be returned to use. Some water softeners automatically switch to the operation cycle. Others have a manual switch. Figure 5.2 illustrates both cycles of the water-softening process—ion exchange and regeneration.

Kinds of Softeners

Although many brands and models of ion exchange units exist on the market, all essentially perform the same with minor differences in extra features, flow rates, etc. Nearly all softeners fall into one of two categories. Timed models have programmable time clocks that regenerate on a predetermined schedule and then return to service. These work well for households on regular water-using cycles but use more water and salt because they regenerate whether the resin needs it or not. Demand-control models, with either electrical or mechanical sensors, usually regenerate after so many gallons of water have been softened. Such models are convenient if you have a fluctuating water-use schedule.

Figure 5.2. A typical water softener showing cation exchange and regeneration.



Maintenance

No matter which model you choose, all water softeners need to be properly maintained. The brine solution must be mixed and stored in the brine tank. Periodic clogging of the resin also requires special attention. For example, if the raw water supply is turbid it may clog the resin with mud and clay. Sometimes normal backwashing with water solves this problem. If not, slowly stir the resin during the backwash cycle to help break up the material. Likewise, bacteria and fungi also form mats in the resin, reducing its effectiveness. Disinfecting the water before softening or periodically cleaning the softener with chlorine bleach eliminates these nuisances. However, read the manufacturer's instructions before adding any chemicals to the unit.

Iron fouling is another common maintenance problem for water softeners. Although colorless, reduced iron is removed by the unit, red-oxidized iron (iron that has been exposed to air or chlorine) clogs the resin. Filtration prior to softening ensures that oxidized iron is not processed in the softener. If the resin has already been fouled, commercial cleaners are available. Again, it is advisable to check the manufacturer's instructions for special precautions.

In some instances, resins cannot be washed of contaminants and need to be replaced. (This should *not* be the case if the resin is periodically regenerated and maintained.) Consult your water softener dealer for information on resin replacement.

Costs

Water-softening costs depend on factors such as installation, maintenance fees, and size of the unit. You can also expect that with more convenience features, the price of the unit will increase. An average range for the hardware only is around $500–$1,500.

Advantages and Disadvantages of Water Softening

As the water treatment industry has grown in the United States, the concept of water softening has often been misconstrued as a purifying, cleansing, or conditioning process. This is due largely to exaggerated advertising and, in part, to consumer misconceptions about water treatment. But the reality is that water softening simply removes hardness minerals and eliminates problems that are a nuisance and not a threat to human health. The decision "to soften or not to soften" is a matter of personal preference—not necessity. However, water softening does have advantages and disadvantages that make this decision a significant one.

Advantages

Most consumers would agree that hard water leaves scales on pots, soap films on skin, and detergent curds in the washing machine. More important, scales can also build up on hot water heaters and decrease their useful life. Soap film and detergent curds in bathtubs and appliances indicate that you are not getting the maximum cleaning action from these products. Soft water not only eliminates these nuisances but also protects appliances and saves cleaning time.

Water softening has other advantages, in addition. It is a well-developed technology that has been used in homes for almost 65 years. The equipment is reliable, effective, and widely available, providing consumers with convenient features and a selective market. The simple technology of softening makes it easy to bypass toilets and outdoor faucets. Finally, softening systems are adaptable for mixing softened and unsoftened water to produce a lower hardness level.

Disadvantages

The major disadvantage of water softening is the potential health risks for people on low-sodium diets. The exchange of hardness minerals for sodium adds 7.5 milligrams per quart for each gpg of hardness removed. In addition, calcium and magnesium are eliminated from the homeowner's diet. This disadvantage can be limited by using potassium salt instead of sodium salt or by only softening hot water and allowing drinking water to be unsoftened.

Maintenance is another consideration. While you can purchase models with special features that do everything but add the salt, you will pay for each additional feature. The trade-off is cost for convenience and you have no long-term guarantee that the special feature will not fail. Depending on the water source, you may have to filter turbid water or disinfect bacteria-laden water—all before it even reaches the softening unit. Finally, if you own a septic system, consider the additional load on your drainage field from backwashing and regeneration. Estimates indicate that about 50–100 gallons of water are used for each regeneration cycle. This may or may not cause hydraulic overload of the septic system.

Shock Disinfection (One-Time Chlorination)

While the following is provided as an overview to inform the homeowner about proper well chlorination, it is strongly recommended that you contact a professional well contractor to effectively and safely perform this procedure for you due to the variable nature of individual wells and water systems.

Bacterial contamination is one of the most common water-quality problems in private water wells and springs. A recent survey of 700 private wells in Pennsylvania found that about 33 percent contained coliform bacteria. Past studies have shown that springs are even more susceptible to bacterial contamination. These bacteria are a potential problem because they may cause serious gastrointestinal illnesses (see Chapter 4). Shock chlorination can be used to disinfect a well or spring that has become contaminated from a one-time incident such as flooding or a dead animal in a well or spring box.

Water Treatment Equipment Concerns

Before shock chlorinating your water system, it is important to determine if any susceptible water treatment equipment, such as a softener, carbon filter, or a reverse osmosis system, is installed in your home. Some water treatment equipment can be damaged or exhausted by high chlorine concentrations in water. Contact your water treatment company or equipment manuals to find out if your equipment should be bypassed during shock chlorination.

When to Shock Chlorinate Your Well or Spring

Shock chlorinate your well or spring:

- After constructing a new well (many well drillers do this as a standard practice)
- After working on an existing well or installing a new submersible pump
- After receiving a positive water test report for coliform bacteria

Disinfection Procedure for Wells

Take the following steps to disinfect a well:

1. *Clear the water:* If your water is cloudy or contains any suspended particles, the well should be pumped until the water clears. Cloudy water greatly reduces chlorine's ability to kill bacteria.
2. *Obtain chlorine:* Unscented household chlorine bleach containing 5.25 percent available chlorine may be used to shock chlorinate private water supplies; however, only chlorine products with label information specifying use in potable water supplies can be recommended. These must be obtained from water treatment vendors or well drilling contractors. Consult Table 5.2 to determine the amount of bleach you will need for your well. Note that the water depth shown in the table refers to the actual depth of water in the well, not the total depth of the well.

   In some cases, it may be difficult to determine the actual depth of water in the well. This information may be stamped on the inside of the well cap or written on the well completion report you received from the well driller. If you are unable to determine the actual depth of water in the well, use a minimum of 0.5 gallon of bleach if you estimate the water depth to be less than 80 feet and the well diameter is 8 inches or less. For wells with greater water depth and diameter, use 1 gallon of bleach. *It is always better to use too much chlorine than too little!*
3. *Apply chlorine to well:* Remove the cap from the top of the well and mix the chlorine with 5 to 10 gallons of water in a nonmetallic container. Be careful to keep the chlorine solution away from your skin and clothing. Slowly pour this solution into the well. Remember to bypass any sensitive water treatment equipment before proceeding. It is recommended to turn off the power to the pumping system for safety before beginning this procedure and to turn the power back on when completed. Also, be aware of wiring connections at the wellhead. It is best not to pour the chlorinated water directly onto any wiring connections or splices.
4. *Mix chlorine within well:* To adequately mix the chlorine solution in the well, run a garden hose from an outside faucet into the well and circulate water into the well, washing down the sides of the casing until a strong odor of chlorine occurs in the water from the hose. It may take from 15 minutes to 1 hour for enough mixing to occur. (Note: If a strong chlorine odor is not noticeable at the hose after thorough mixing, too little time was allotted or not enough chlorine was added to the well—more chlorine should be added.) Close the hose faucet and replace the well cap.
5. *Turn on inside faucets:* Inside the home, turn on each faucet throughout the house (one at a time) until a strong chlorine odor is noticeable in the water. You should run both the cold and hot water at each faucet until you notice the strong chlorine odor. (Note: It may take quite some time for a

Table 5.2. Amount of household bleach required to disinfect a water well.

	Water diameter (inches)					
Water depth (feet)	**6**	**8**	**10**	**24**	**32**	**36**
10	1 c	1 c	2 c	3 qt	4 qt	6 qt
20	1 c	2 c	4 c	5 qt	8 qt	10 qt
30	2 c	4 c	3 pt			
40	1 pt	2 pt	4 pt			
60	2 pt	3 pt	6 pt			
80	2 pt	4 pt	7 pt			
100	3 pt	5 pt	4 qt			
150	5 pt	4 qt				

c = cup, pt = pint, qt = quart

chlorine odor to be noticed at the first cold and hot water faucet that is turned on, owing to the significant volume of the hot water heater.) Once the odor is noticeable, turn off the faucet. This will ensure that the chlorinated water has been dispersed throughout the plumbing system. If a strong chlorine odor is not apparent at any of the faucets, more mixing may need to occur or more chlorine should be added to the well (see step 4 above).

6. *Provide contact time:* Allow the water to sit in the plumbing for at least 12 hours.

7. *Purge high-chlorine water from the well:* The first water used following shock chlorination is of a chlorine concentration similar to that used for bleaching laundry. The first water may also appear very discolored owing to iron or other metals from the well casing or in the water. Disposal of this high-chlorine water must be done carefully. If your home is connected to a central sewer system, you can dispose of the water by letting each of the faucets in the home run until the chlorine smell dissipates to an acceptable level. Note that complete removal of the chlorine smell may take several days of normal water use. Do not use water that has a strong chlorine odor for bathing, cooking, washing, or drinking. This water may cause skin irritation and damage to clothing.

   If your house has a septic system, do not run all the chlorinated water into the system as it may overload the system. In this case, use a garden hose to pump some of the chlorinated water to a safe disposal site. Bare ground is the best disposal area, or the water can be sprinkled on grass. Avoid applying the high-chlorine water to foliage of flowers or ornamental shrubbery or near any water body containing fish.

8. *Retest your water:* After following the procedures outlined above, retest your well water for coliform bacteria approximately 10 to 14 days after the shock chlorination. If no coliform bacteria are present, wait an additional two to three months and have the water tested again. If the bacteria return in either of these subsequent tests, a continuous disinfection treatment system will be necessary.

Disinfection Procedure for Springs

Shock chlorination of springs is difficult and rarely successful because the water often runs through the spring box too quickly to provide adequate contact with the chlorine to kill bacteria. Disinfection of the spring box should not be attempted if the spring overflow (the water that does not enter the house) enters a stream, pond, or wetland area where high-chlorine water may cause environmental damage, especially a fish kill.

1. *Wash spring box walls:* Shock chlorination of a spring can be attempted by mixing 0.5 cup of household bleach with 5 gallons of water to scrub the walls.

2. *Disinfect spring box water:* Estimate the volume of water in the spring box in gallons (there are 7.5 gallons of water in each cubic foot of storage). For each 100 gallons of water in the spring box, create a disinfection solution by mixing about 3 pints of chlorine solution with a few gallons of water. Pour the disinfection solution into the spring box.

3. *Follow well disinfection steps 5–8:* Use steps 5-8 on the previous page to disinfect each of the faucets in the home and run the water to a disposal site the next day. Because of the prevalence of bacteria in springs and the difficulty in adequately shock chlorinating the spring source, installing continuous disinfection treatment equipment for spring sources with coliform bacteria is often necessary.

Continuous Disinfection (Continuous Chlorination)

Municipal water treatment plants throughout the United States continuously add chlorine to ensure that their water is free of bacteria. Chlorination treatment systems are basically composed of a feed system that injects a chlorine solution (sodium hypochlorite or calcium hypochlorite) into the water ahead of a storage tank. Most chlorinators use positive displacement feed pumps to meter the chlorine into the water. Other units may use suction-type chlorinators or pellet droppers to deliver the chlorine.

The raw water entering the chlorinator should be perfectly clear or free of any suspended sediment or cloudiness in order for the chlorine to effectively kill the bacteria. A sediment filter is routinely installed ahead of the chlorinator to remove small amounts of suspended material.

The chlorine that is injected into the water is consumed as it kills bacteria. The chlorine is also consumed by impurities in water such as iron, hydrogen sulfide, and organic materials. The amount of chlorine needed to kill bacteria and oxidize all the impurities in the water is known as the *chlorine demand.* Thus, the total amount of chlorine that must be injected into the water depends on the chlorine demand of the raw water. Other water characteristics such as pH and temperature also affect the amount of chlorine that must be injected into the water. The goal of continuous chlorination is to provide enough chlorine to satisfy the chlorine demand and still allow for approximately 0.3 to 0.5 milligrams per liter of residual chlorine in the water. This residual chlorine is then available to kill bacteria that may enter the water after the chlorinator.

The time required for the chlorine to kill bacteria is known as the *contact time*. The required contact time varies depending on water characteristics, but a general rule of thumb is to provide approximately 30 minutes of contact time. Standard pressure tanks are usually not large enough to provide sufficient contact time, so a larger intermediate holding tank may need to be installed. Sufficient contact time can also be achieved by running the water through a series of coiled pipes. Contact time requirements can be shortened by increasing the chlorine dose (superchlorination), but this may require the addition of a carbon filter to remove the objectionable chlorine taste and odor.

Continuous chlorination treatment systems require significant maintenance. Chlorinators must be routinely checked to ensure proper operation and chlorine supplies must be continually replenished. Both liquid and solid forms of chlorine are poisonous and irritants that must be handled according to specific safety measures.

Ultraviolet Light Disinfection

Ultraviolet (UV) light has become a popular option for disinfection treatment because it does not add any chemical to the water. However, UV light units are not recommended for water supplies where total coliform bacteria exceed 1,000 colonies per 100 mL or fecal coliform bacteria exceed 100 colonies per 100 mL.

The unit consists of a UV light bulb encased by a quartz glass sleeve (Figure 5.3). Water is irradiated with UV light as it flows over the glass sleeve. The untreated water entering the unit must be completely clear and free from any suspended sediment or turbidity to allow all of the bacteria to be irradiated by the light. In addition, inorganic constituents such as iron, manganese, and hardness can coat the glass sleeve and, thus, must be below certain specified levels for the UV unit to effectively treat the water. Check the manufacturer's recommendations to see if pretreatment is required before installing a UV unit.

A sediment filter is often installed ahead of the UV unit to remove any sediment or organic matter before it enters the unit. The quartz glass sleeve must also be kept free of any film. Overnight cleaning solutions can be used to keep the glass sleeve clean, or optional wipers can be purchased with the unit to manually clean the glass. Water with a high hardness (calcium and magnesium) may also coat the sleeve with scale (a whitish deposit of hardness), which may require routine cleaning or addition of a water softener. The unit also requires electricity and will cause a small but noticeable increase in your electric bill (perhaps $2 to $4 per month). The disadvantage of this system is that it only kills bacteria inside the unit and does not provide any residual disinfectant for bacteria that may survive or be introduced into the plumbing after the UV light unit.

Maintenance requirements are minimal for UV units, but the light bulb slowly loses intensity over time and requires replacement about once a year. Some units come equipped with a UV light intensity sensor that can detect when the bulb is not emitting sufficient UV light. These sensors add to the initial cost of the unit but may pay for themselves by preventing premature bulb replacement.

Oxidizing Filters for Removing Iron, Manganese, and Hydrogen Sulfide

Oxidizing filters both oxidize and filter iron, manganese, and hydrogen sulfide in one unit. The filter is usually comprised of manganese-treated greensand, although other materials such as birm can also be used. In the case of a manganese greensand filter, the filter media is treated with potassium permanganate to form a coating that oxidizes the dissolved iron and

Figure 5.3. A typical UV light installation with a small canister sediment filter ahead of the UV light unit.

manganese and then filters them out of the water. Because these units combine oxidation and filtration, they can be used to treat raw water with dissolved and/or oxidized iron and manganese along with hydrogen sulfide gas.

Manganese greensand filters require significant maintenance including frequent regeneration with a potassium permanganate solution. In addition, these units require regular backwashing to remove the oxidized iron and manganese particles. The potassium permanganate solution used for regeneration is toxic and must be handled and stored carefully using specific safety measures.

When properly maintained, manganese greensand filters are extremely efficient for moderate levels of both dissolved and oxidized iron and manganese. They are generally recommended when the combined iron and manganese concentration is in the range of 3 to 10 mg/L. Keep in mind that the frequency of maintenance (backwashing and regeneration) increases as the metals concentration increases. Oxidizing filters can be used to remove up to 2-3 mg/L of hydrogen sulfide. The higher the concentration of hydrogen sulfide, however, the more frequently the unit will need regeneration and backwashing.

Birm filters are similar to manganese greensand, but they do not require regeneration because they use oxygen present in the raw water to oxidize the metals. As a result, the raw water must contain a certain amount of dissolved oxygen, and the pH should be at least 6.8 for iron removal and 7.5 for manganese removal. Even under ideal conditions, manganese removal efficiency is highly variable with birm filters. Birm filters do require backwashing to remove accumulated oxidized metal particles.

When combined levels of iron and manganese exceed 10 mg/L, the most effective treatment involves oxidation followed by filtration. In this process, a chemical is added to convert any dissolved iron and manganese into the solid, oxidized forms that can then be easily filtered from the water. Chlorine is most commonly used as the oxidant, although potassium permanganate and hydrogen peroxide can also be used. A small chemical feed pump is used to feed the chlorine (usually sodium hypochlorite) solution into the water upstream from a mixing tank or coil of plastic pipe. The mixing tank or pipe coil is necessary to provide contact time for the iron and manganese precipitates to form. It may be necessary to install an activated carbon filter to remove the objectionable taste and odor from the residual chlorine. Chlorine is not recommended as an oxidant for very high manganese levels because a very high pH is necessary to completely oxidize the manganese.

Significant system maintenance is required for these units. Solution tanks must be routinely refilled and mechanical filters need to be backwashed to remove accumulated iron and manganese particles. If a carbon filter is also installed, the carbon needs to be replaced occasionally as it becomes exhausted. The frequency of maintenance is determined primarily by the concentration of the metals in the raw water and the amount of water used.

Ozonation

Ozonation eliminates bacteria, viruses, microorganisms, colors, odors, and tastes. It can oxidize iron, manganese, and hydrogen sulfide, and it can precipitate some metals.

In recent years, ozonation has received more attention as a method for treating water-quality problems including bacterial contamination. Like chlorine, ozone is a strong oxidant that kills bacteria, but it is a much more unstable gas that must be generated on site using electricity. Once the ozone is produced, it is injected into the water where it kills the bacteria. Ozonation units are generally not recommended for disinfection because they are much more costly than chlorination or UV light systems. They may be useful where multiple water-quality problems must be treated, such as disinfection in combination with removal of iron and manganese.

Ozonation does not typically require much maintenance, but the health implications for those using it are not fully understood.

Chemical Injection

Various chemicals can be injected into the water line to treat a variety of water pollutants. Continuous chlorination (described above) is one special type of chemical injection that is used to treat bacteria problems. Chlorine can also be injected to oxidize metals and hydrogen sulfide odor in water. Thus, direct injection of chlorine can be very efficient for treating metals, hydrogen sulfide, and bacteria when all are present in water. Chemical injection often involves the use of soda ash (for corrosion control), potassium permanganate (for metals and hydrogen sulfide), or polyphosphate (for iron).

Injection of soda ash or other basic solutions is sometimes used to treat extremely corrosive waters that exceed the capacity of standard acid neutralizing filters. This treatment system is simple and inexpensive and does not increase water hardness. Since the unit is installed ahead of the pressure tank, there is no reduction in water pressure that sometimes occurs with neutralizing filters. There is significant maintenance, including filling solution tanks and maintaining the feed pump. Soda ash is preferred over sodium hydroxide because it is safer to handle. Sodium hydroxide is extremely caustic and must be handled using accepted safety practices.

Another common chemical injection is potassium permanganate to treat hydrogen sulfide, iron, and manganese. Much like chlorination described above, a potassium permanganate solution can be injected into the water with a small chemical feed pump installed ahead of a holding tank that provides at least 15 minutes of contact time. The oxidized sulfur particles can then be removed using a manganese greensand or zeolite filter. The filter media also allows for polishing of unoxidized hydrogen sulfide (see "Oxidizing Filters"). Like chlorination, this method is excellent for high concentrations of hydrogen sulfide above 6.0 mg/L. However, the potassium permanganate solution is an irritant and poison that must be handled and stored according to standard procedures.

A final chemical treatment, in which the chemicals are often injected directly into water, is the use of polyphosphates to sequester dissolved iron concentrations less than about 2 mg/L. Phosphate addition is generally ineffective in treating manganese. The phosphate is fed into the water using a chemical feed pump that often requires trial-and-error dose adjustments. In this case, the iron is surrounded or "sequestered" by the phosphate and is not actually removed from the water.

This process has some major drawbacks. Although the sequestered iron does not cause objectionable stains, it still gives the water a metallic taste. In addition, if too much phosphate is added to the water, it gives the water a slippery feeling and may also cause diarrhea. The polyphosphate may also be degraded in a water heater, resulting in release of sequestered iron.

Activated Alumina

Activated alumina (AA) filtration involves the passage of water through an alumina media. Arsenate is very strongly attracted to the alumina material as the water passes through the filter. Large AA treatment devices or point-of-entry (POE) devices can be used to treat all household water, or smaller point-of-use (POU) filters can be used to remove arsenic at a single tap in the home. AA is the preferred treatment method if your water has high total dissolved solids (TDS) or high sulfate concentrations. A disadvantage of AA filters is that they must be regenerated using strong acid and base solutions that are undesirable for home storage and handling. In addition to periodic regeneration, the alumina filter material must be replaced every one to two years.

Granular Activated Carbon (GAC)

GAC is commonly used to treat many water pollutants because it has a large treatment surface that allows for many chemicals to be adsorbed and removed from water. Many small faucet filters are filled with a tiny amount of GAC that can effectively polish water to remove small amounts of objectionable tastes. The most common use of these small faucet filters is to remove chlorine taste and odor from water at one sink.

Larger, whole-house or POE GAC treatment units can be installed to remove many organic pollutants like fuel oil, gasoline, solvents, and pesticides. These filters are normally large fiberglass tanks filled with 1 to 2 cubic feet of GAC. When removing pollutants, the GAC has a limited lifetime as the carbon becomes spent by the incoming pollutants. The life of the carbon is related to the concentration of the pollutants in the water, the size of the carbon filter, and the amount of water put through the filter. You should periodically retest your treated water to ensure that your carbon filter is working properly. Generally speaking, GAC will need to be replaced about every six months under typical operating conditions. Keep in mind that removal of hazardous materials with a GAC filter produces a hazardous spent carbon material that must be disposed of properly. Contact your local Department of Environmental Protection office to learn how to safely dispose of a spent carbon filter.

Because of the carbon's fine particle size, it also easily clogs with sediments or other contaminants present in the water. Some GAC units come with a special backwashing feature for removing sediment. These eventually reduce the carbon's effectiveness in treating pollutants. Eliminating the sediment source or placing a sediment filter ahead of the GAC tank provides the best protection against clogging. Also keep in mind that GAC filters are an excellent growth media for bacteria. As a result, only disinfected water or water known to be free of coliform bacteria should be allowed through a GAC filter.

GAC is also a popular method for treating radon in water. Unlike other pollutants, radon does not consume carbon. Instead, the radon gas degrades in the filter. However, experts disagree on GAC's ability to treat radon in water. Some estimates show that it should not be used if waterborne radon levels exceed 30,000 pCi/l. Other experts say 5,000 pCi/l. The best way to decide is to have your water tested and then investigate GAC filters that have high removal efficiency rates at the level found in your water.

If you do decide to purchase a unit, select a filter size that matches water use and conditions. According to EPA, a 3-cubic-foot unit can handle as much as 250 gallons of water per day and effectively reduce radon levels. Typical water use in the home ranges from 50 to 100 gallons per person per day. Size and special features both affect costs, which can start at $700 depending on the unit. They can be purchased commercially through water treatment dealers. Be sure to investigate thoroughly the company and its products before purchasing any unit. GAC filters will remove radon indefinitely, providing that sediments or organic pollutants have not clogged the filter.

A major drawback to using GAC filters is that if radon is present, the filter becomes radioactive as it picks up the gas. Lead-210 (a radon daughter) builds up on the carbon filter and then gives off its harmful radioactive rays as it continues to decay. **IT IS EXTREMELY IMPORTANT TO PLACE THE UNIT OUTSIDE THE HOME OR IN AN ISOLATED PART OF THE BASEMENT. A SHIELD MAY BE REQUIRED IF RADON LEVELS ARE HIGH (GREATER THAN 30,000 PCI/L).**

GAC filters may produce a radiation problem when the device is used to remove other contaminants. For example, a homeowner installs a GAC unit to remove a pesticide without testing the water for radon. The GAC unit sits under the sink, harmlessly removing the problem contaminant. Right? Wrong. Unfortunately, what the homeowner doesn't know is that the water supply has very high radon levels. So while the GAC traps the pesticide it also traps radon, thus producing a radioactive filter and a radiation hazard.

GAC can also be used to remove small amounts (less than about 1.0 mg/L) of hydrogen sulfide gas from water. In most cases, GAC units are installed in combination with other hydrogen sulfide treatment (oxidizing filters, etc.) to "polish" the water and remove small amounts of residual hydrogen sulfide that are not removed during the primary treatment.

More recently, other forms of activated carbon known as "catalytic carbon" have been developed for hydrogen sulfide treatment. Catalytic carbon first adsorbs the hydrogen sulfide then oxidizes the gas much like an oxidizing filter. As a result, catalytic carbon units can be used to treat much higher hydrogen sulfide concentrations than activated carbon filters. Maintenance requirements are less than oxidizing filters because no chemicals are added, but backwashing is still necessary. Catalytic carbon requires a minimum of 4.0 mg/L of dissolved oxygen in the source water. Some groundwater supplies may need pretreatment to increase the dissolved oxygen concentration.

Distillation

Distillation is an older method of removing contaminants from drinking water. It involves boiling water, collecting the steam, and allowing it to cool. The treated water resulting from this process is free of most contaminants. Distillation can be used to disinfect water, remove many organic and inorganic contaminants, and reduce the concentration of toxic metals. Distillation completely removes from the water all dissolved solids, which may affect the water's taste and make it more corrosive.

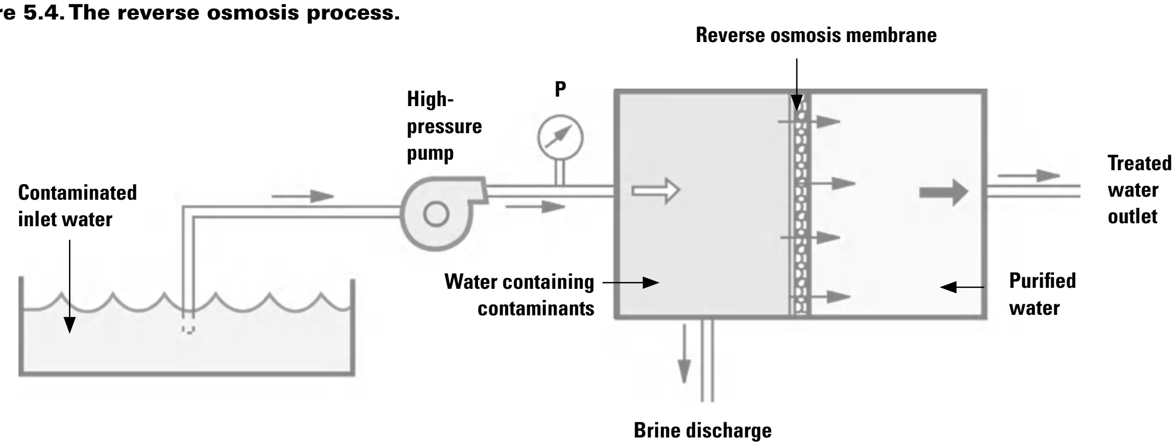
It is difficult to determine the maintenance schedule for a distillation unit until it is installed. The quality of the water being treated will determine how often it needs maintenance. Other considerations include the costs associated with using more electricity; in addition, these units produce a considerable amount of heat and do not remove certain volatile chemicals.

Reverse Osmosis

Reverse osmosis is another common treatment that can effectively remove most inorganic pollutants (such as arsenic, barium, cadmium, chloride, copper, fluoride, lead, manganese, mercury, and nitrate). Figure 5.4 shows the reverse osmosis process. As water enters the unit under pressure, it pushes against a cellophane-like plastic sheet or cellulose—also called a semipermeable membrane. The membrane acts like a sieve, leaving ions on one side and allowing ion-free water to pass through the membrane. How well the membrane filters the water is measured by the rejection rate.

While a simple reverse osmosis filter includes just a storage tank and a membrane, other treatment processes are usually included in the overall reverse osmosis device. For example, a sediment filter is often added to remove particles before the water encounters the sensitive membrane, and an activated carbon filter is often included after the membrane to polish the water and remove trace pollutants that may still

Figure 5.4. The reverse osmosis process.



impart tastes or odors to the water. As a result, the overall reverse osmosis unit often appears as three filters (sediment, membrane, and carbon filters). Units usually operate at the point of use—kitchen tap, bathroom sink, etc. Many factors like water pressure and temperature, membrane selection, and proper maintenance influence performance. Carefully review these factors with a water specialist before making purchasing decisions.

While reverse osmosis can be effective at removing many inorganic pollutants, it has disadvantages. Reverse osmosis is expensive, with initial costs ranging from $300 to $900. Added to the equipment costs are the high energy costs for operation. Reverse osmosis is also a slow, inefficient process, sometimes producing only a few gallons a day of purified water, while wasting up to 90 percent of the incoming water. This is especially true for low pressure systems.

Other Treatment Options

Boiling (Disinfection)

Boiling water for about one minute effectively kills bacteria. This method is frequently used to disinfect water during emergencies or while camping. Boiling is time and energy intensive, however, and only supplies small amounts of water. It is not a long-term or continuous option for water supply disinfection.

Water System Flushing (Lead or Copper)

Excessive amounts of lead and/or copper in water from corrosion of metal plumbing can sometimes be avoided through water system flushing. This flushing simply involves running the water from the faucet for a minute or two to purge the contaminated water from the plumbing and draw fresh, unpolluted water in from the well or spring. This can be effective because corrosion of copper and lead normally takes an hour or more to build up as the water sits in contact with the metals.

Flushing is only necessary if the water has been in contact with the plumbing for at least one hour. If you choose this method, you should collect a water sample after you have run the water for one minute and have it analyzed for copper and lead to ensure that they are reduced to safe concentrations. You can conserve water by flushing the plumbing system in the morning and filling a container with drinking water for use during the day. Flushing can be a simple and inexpensive solution for excessive lead and copper in drinking water. But keep in mind that the continual corrosion of metal plumbing may ultimately cause leaks to develop in the pipes. If this occurs, other corrosion treatment (acid neutralizing filter, soda ash injection, etc.) or replacing the metal plumbing with approved PVC plastic is necessary.

Water Heater Adjustment (Hydrogen Sulfide)

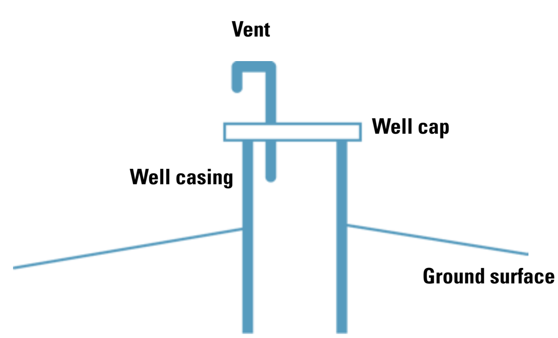
If the rotten egg odor occurs only in the hot water, the production of hydrogen sulfide can often be simply treated by removing the magnesium rod from the hot water heater. This rod often provides a chemical catalyst for the production of hydrogen sulfide from naturally occurring sulfates in the water. The magnesium rod is present in the hot water heater as an anti-corrosion device. Removing it could increase corrosion and reduce the life of the hot water heater, and will likely void the manufacturers' warranty. Replacing the magnesium rod with an aluminum rod should eliminate the rotten egg odor while maintaining corrosion protection for the heater.

Well Vents (Methane Gas)

Inexpensive vents can remove methane from some groundwater wells. A variety of vented caps are available from most well drillers for less than $100. Be sure to install these caps correctly to prevent insects and small animals from entering the well. Most have a screen and are turned down (see Figure 5.5).

If the well cap is buried or in a covered pit, the casing should be extended above the ground surface and subsequently be fitted with a cap and vent. Basement wells are especially problematic because the methane escapes directly into your home. You must fit the well with a sealed cap to prevent this leakage. The vent should then extend through the basement wall to the exterior of your house. Similarly, a vent can be installed on the pressure tank to allow methane gas to be removed and vented to the outside of the home. Local plumbing codes may include venting requirements. Contact a water-well professional to determine the best method.

Figure 5.5. Removal of methane gas using well vents.



Sediment Filtration (Various Contaminants)

Sediment filters come in many sizes and varieties. The simplest are very small cartridge filters commonly installed ahead of ultraviolet lights and other treatment units to remove sediment that might interfere with these treatment processes. These simple, inexpensive cartridge filters remove large sediment and metal particles, but they have very limited capacity.

Larger POE sediment filters are also available to treat much larger amounts of water and remove much smaller particles from water. They may even be constructed of very fine media that trap small particles like bacteria, cysts, and sediment. Sand, diatomaceous earth, spiral wound fiber, ceramic, and activated carbon are five common media used for filtration.

Although filters are widely believed to be a failsafe treatment, they are ineffective unless properly maintained and operated. Large sediment filters must be routinely backwashed to clean and restore their filtering capacity, while small cartridge filters must be replaced. The frequency of backwashing or replacement is often determined through trial and error. As sediment filters become saturated, water pressure is reduced to the home as water has a tougher time flowing through the filter. Once water pressure is noticeably reduced, you can conclude that backwashing or replacement is necessary.

As mentioned in the discussion on GAC filters, all sediment filters are excellent media for bacterial growth. If undisinfected water is used, filters are susceptible to bacterial growths that plug and coat the filters, reduce the filtering capacity, and create a source of contamination. For this reason, only disinfected water should be filtered. Filters must also be cleaned regularly and replaced. Filters such as the tap-mounted type must be changed at least every six months. Read the manufacturer's instructions to make sure that you are properly maintaining your filter.

Magnetic Devices (Not Recommended)

Typically these devices are permanent magnets or electromagnets that attach to waterlines entering homes and businesses to "purify" or "condition" water supplies. Manufacturers adopt a variety of commercial names for their products from the complex—"patented directional controlled magnet," "Permcore," and "Magnetizer"—to the simple—"metal bar" or "plug-in treatment device."

Such devices purportedly use electromagnetic fields to change the molecular makeup of various water constituents like calcium and iron to other more "inert" forms. The claimed result is a reduction or elimination of water contaminants. One manufacturer describes the magnetic treatment processes this way: "Water and minerals are subjected to violent intramolecular vibrations and shock at the same time magnetic energy is being added, the mineral's crystallization is being upset and cohesion is being broken." Sales representatives often persuade potential customers that they can rely on magnetic treatment devices to provide lifetime, energy-free home water treatment.

The claims put forth by these devices' manufacturers and sales representatives are without validity. They do not refer to standard physical, chemical, or biological water treatment processes. Therefore, several researchers have conducted performance evaluations of the equipment and concluded that there is virtually no valid scientific data to support any water treatment benefit from magnetic devices.

WATER, WATER, EVERYWHERE?

Pennsylvania has many water resources. In an average year, about 34 trillion gallons of precipitation falls on the state. Much of this water flows through 83,000 miles of surface streams and thousands of ponds, lakes, and reservoirs. At any given moment, approximately 47 trillion gallons of water are stored beneath the surface as groundwater. It's easy to see why Pennsylvania is referred to as a "water-rich" state. As a result, we have become accustomed to adequate supplies for all uses. For most of us, water is never more than a few steps away. We only need to open a faucet, press a button, or turn a cap to quench our thirst.

WATER USE IN PENNSYLVANIA

In 1995, approximately 9,610 million gallons per day (MGD) of water were withdrawn in Pennsylvania (see Table 6.1). Over half was used to cool thermoelectric power generators. Other major water uses were for industrial and domestic activities.

The values in Table 6.1 include the total amount of water withdrawn for a particular purpose. Included in this total are both *consumptive* and *nonconsumptive* water uses. Nonconsumptive use involves the withdrawal, use, and subsequent return of the water with little or no change in quantity. Consumptive use includes activities that evaporate water. These losses are relatively small around the home (usually less than 10 percent), but nearly all of the water used for irrigation is consumptive.

Domestic water consumption has changed dramatically in Pennsylvania during the last 100 years. In 1900, only 5 million people lived in the state and each used about 5 gallons each day (25 MGD). By 1995, there were over 12 million residents, each using about 62 gallons per day (740 MGD). While long-term consumption has increased significantly, we have made progress in conserving water in the United States (see Figure 6.1). The advances made through improved water use efficiency show the potential conservation possible with continuous effort.

Water-use habits have changed dramatically since the early 1900s. Average water use by each Pennsylvanian has decreased slightly from 1985, when it was estimated to be about 65 gallons per person per day. Population shifted at that time, moving from urban centers to suburban and rural areas. These changes are adding pressure on water sources in some parts of the state while reducing use in others.

Sufficient quantities of high-quality water require a large investment in equipment, pipes, and storage facilities. A recent report by the General Accounting Office indicates that communities could save hun-

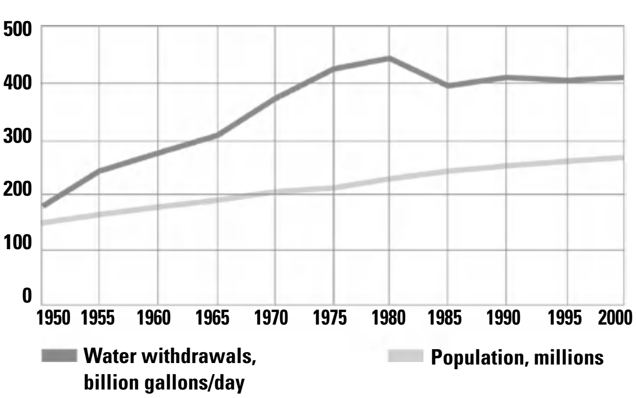
Table 6.1. Total water withdrawals and consumptive water use in Pennsylvania in 1995.

Purpose	Water use (MGD*)	Consumptive use (MGD)
Thermoelectric	5,930	239
Industrial	1,870	158
Domestic	740	74
Commercial	247	11.5
Mining	182	14
Livestock	55.3	41
Irrigation	15.9	15.9

*MGD = million gallons per day

Source: Ludlow, R. A., and W. A. Gast. 2000. Estimated water withdrawals and use in Pennsylvania. U.S. Geological Survey Fact Sheet 174-99, Washington, D.C.).

Figure 6.1. Trends in population and water withdrawals in the United States from 1950 to 2000. *(Hutson et al. 2000)*



dreds of millions of dollars on water and sewage facilities through water conservation.

Washing clothes, washing dishes, bathing, and flushing the toilet account for almost all the water consumption in homes. Water used for drinking and cooking is insignificant compared to the amount we use for waste removal. Table 6.2 details typical domestic uses.

Toilets use the most water; however, this use is much lower than it was before the advent of the low-flush (1.6 gal/flush) toilet. Washing clothes consumes the second largest amount of water.

After this water has been used, it becomes wastewater and drains to a sewer line. These lines run under the streets to sewage treatment plants. Wastewater usually flows in these pipes by gravity, and they are called gravity sewers. In older towns, storm drains are connected to this system so that rainwater also travels to the sewage treatment plant. Newer collection systems separate storm water into storm sewers and wastewater into sanitary sewers to avoid this problem.

At the sewage treatment plant, the wastewater is treated. This process includes removing nutrients and is quite costly.

On-lot disposal systems are also widely used. The first part, the septic tank, is a concrete tank into which flow wastes from an individual home. In it, solids settle to the bottom and bacteria begin to break down organic matter. The overflow is piped to an underground drainage field where organisms complete the breakdown of the sewage. Unfortunately, on-lot systems only work well in soils that can accept the effluent at an adequate rate. The less wastewater moving through this system, the better it works.

Table 6.2. Average domestic water use in the United States.

Plumbing fixture or appliance	Use (gal per person per day)
Toilet	18.5
Clothes washer	15.0
Shower	11.6
Faucets	10.9
Leaks	9.5
Other	1.6
Bath	1.2
Dishwasher	1.0
Total	69.3

Source: Adapted from Mayer et al. Residential end uses of water. 1999. American Water Works Association Research Foundation.

OUTDOOR WATER USE

Outdoor water use in the United States averages about 32 gallons per person per day. This value varies considerably in different regions. In western states, where precipitation is low, outside consumption may exceed 100 gallons per person per day. In eastern states, like Pennsylvania, outdoor water use is much lower—generally less than 10 gallons per person per day—because natural precipitation is more abundant.

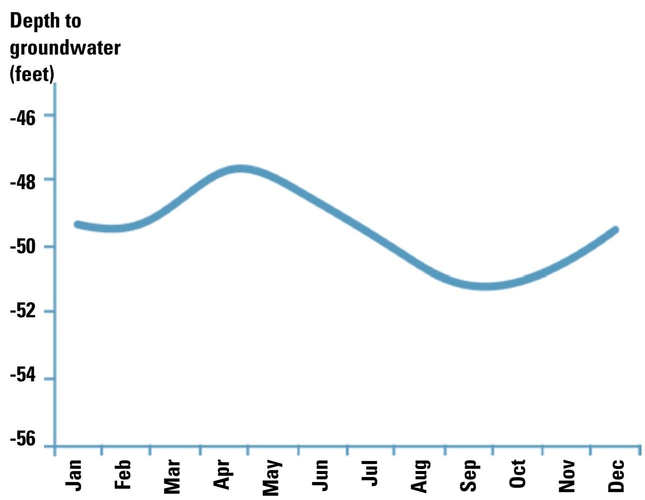
MANAGING YOUR WELL DURING A DROUGHT

In recent years, frequent droughts have caused severe water shortages in parts of Pennsylvania. Droughts can be especially stressful for the one million rural homeowners who rely on private wells for their water supply. These individual wells tap groundwater aquifers that cannot easily be seen or monitored. The invisible nature of groundwater leads to an uneasy feeling among homeowners relying on wells that their water supply could dry up without warning during a drought. This section explains the typical variation of water in wells and gives some hints for estimating groundwater levels near your well and managing your water during drought.

The Normal Cycle of Groundwater Levels

The water level in a groundwater well fluctuates naturally during the year (Figure 6.2). Groundwater levels tend to be highest during March and April in response to winter snowmelt and spring rainfall. The movement of rain and snowmelt into groundwater is known as "recharge." Groundwater levels usually begin to fall in May and continue to decline during the summer.

Figure 6.2. Natural groundwater fluctuation during the year in a typical Pennsylvania water well. *(Swistock and Sharpe, 2005)*



Groundwater recharge is limited during late spring and summer because trees and other plants use the available water to grow. Natural groundwater levels usually reach their lowest point in late September or October. In late fall, after trees and plants have stopped growing and before snow begins to fall, groundwater levels may rise in response to rainfall and recharge. Groundwater recharge persists through the fall until cold temperatures produce snowfall and frozen soil that limit water's ability to infiltrate the ground. Groundwater levels during winter may be stable or fall slightly until spring snowmelt and rainstorms start the annual cycle again. Given this natural cycle of groundwater, most problems with wells tend to occur in late summer or early fall when groundwater levels naturally reach their lowest levels.

The natural fluctuation of groundwater levels illustrated in Figure 6.2 tends to be most pronounced in shallow wells. As a result, shallow wells are usually more susceptible to drought than deeper wells. Shallow, hand-dug wells, for example, are often the first to dry up during drought. Although deeper wells may be slower to suffer from drought conditions, they may also take longer to recover after a drought has occurred.

Can Land-Use Changes Affect My Well's Susceptibility to Drought?

Dramatic changes have been made to the landscape in many rural areas of Pennsylvania. Increasing development and rural population growth will likely continue in the future. Existing rural residents often worry that these changes may create competition for groundwater and might increase their well's susceptibility to drought. It is unlikely that small numbers of new homes will cause significant changes in groundwater levels. However, more dramatic land-use changes that tap large amounts of groundwater or prevent recharge from occurring over a wide area could make existing wells more susceptible to drought. This is especially true in areas where mining is occurring or where large paved areas prevent rainfall and snowmelt from recharging groundwater.

How Can I Monitor Groundwater Levels?

Direct determination of the groundwater level in your well is difficult and usually requires using a water level meter. These meters are comprised of an electrical probe attached to the end of a measuring tape. The probe is lowered into the well until a display or light indicates that it has reached water. The depth to water is then read directly from the measuring tape. These instruments generally cost $300 or more depending on the anticipated length of tape needed.

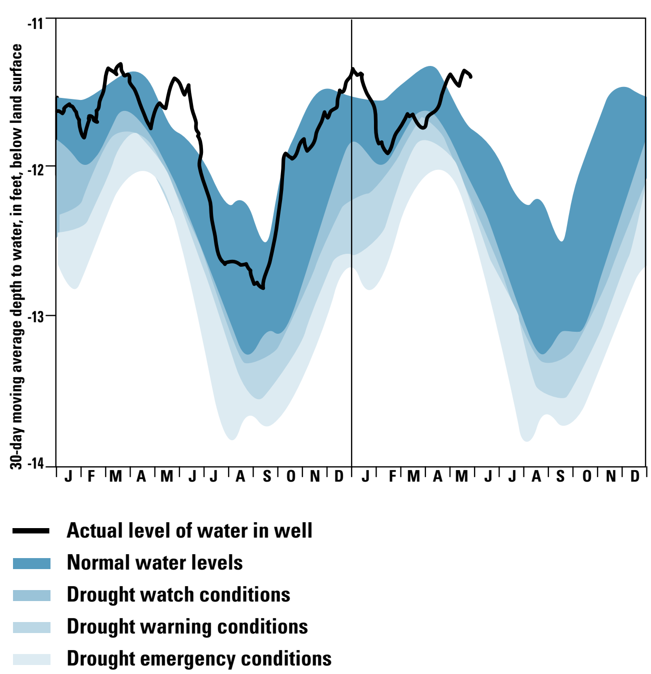
There are other less direct but more practical methods for determining the status of your well water supply. In recent years, the U.S. Geological Survey (USGS) has developed a Web-based system to access water levels from a group of monitoring wells in Pennsylvania. The USGS presently measures wells in every county. It has developed a Web page that allows viewers to access current and historic water levels in each of their monitoring wells. An example from the Adams County monitoring well is shown in Figure 6.3. This information, although not specific to your well, will allow you to observe the general trend in groundwater levels for your area. A list of the available monitoring wells by county is available at pa.water.usgs.gov.

Once you access this page, go to "Pennsylvania Current Streamflow and Ground-Water Depth Duration Graphs." Choose the well nearest to your house and select the "30-Day Graphs" to view up-to-date groundwater conditions in your area.

You can also view current groundwater levels and data for the past seven days for each monitoring well by selecting "current conditions" from the Web site listed above.

Finally, you may be able to learn more about your local groundwater conditions by contacting local well drillers and neighbors. Well drillers are continually drilling new wells and, therefore, may have knowledge of groundwater levels near your well. They may also have installed new submersible pumps in nearby wells that allow them to document the existing groundwater level. Similar discussions with neighbors who have had new pumps installed or had new wells drilled may provide valuable information about the groundwater level.

Figure 6.3. A sample graph of groundwater levels in the Adams County USGS monitoring well during 2000 and 2001. *(U.S. Geological Survey)*



How Can I Conserve Water?

Water conservation measures become critical during times of drought. Homeowners relying on private wells should begin to conserve water as soon as drought conditions occur. Water use within the home can be significantly reduced by changing habits and by installing water-saving devices.

In emergency situations, changes in water-use habits can provide quick reductions in water use. Examples might include flushing the toilet less often, taking shorter showers, only washing full loads of dishes or laundry, and collecting water from roof gutters for outside use. It is also important to note that certain drought declarations may require water-use reductions or restrictions on water use. For example, a "drought emergency" declaration bans the nonessential use of water such as for car washing and lawn watering. These regulations apply to everyone, including homeowners with private wells. For more information on ways to save water around the home, refer to "Water Conservation for the Homeowner" later in this chapter.

What Can I Do If My Well Runs Dry?

There are a number of reasons why a well may quit producing water. The most frequent cause is a malfunctioning or worn-out submersible pump. Other electrical problems such as a malfunctioning electrical switch at the pressure tank may also cause a loss of water. Pressure tanks also need to be replaced from time to time. Water-quality problems like iron bacteria and sediment may also clog the well and severely restrict water flow from the well. A professional well contractor or competent plumber should be consulted to determine the exact cause of the problem.

Under persistent dry weather conditions, the water level in your well may drop below the submersible pump, causing a loss of water. In some cases, the water level may only temporarily drop to the pump intake when water is being frequently pumped from the well during showers or laundry. Under these conditions, you may be able to continue using the well by initiating emergency water conservation measures and using water only for essential purposes.

If the water level permanently drops below the submersible pump, it may be possible to lower the submersible pump within the existing well. Usually this only provides a short-term solution to the problem. More permanent solutions require either deepening the existing well or drilling a new well. Be aware that deepening an existing well may not increase the well yield and could produce water of different quality characteristics. You should consult a local well driller or professional hydrogeologist to determine the best solution for your situation.

Proper management of private wells during droughts will become more important as competition for water in rural areas of Pennsylvania increases. By monitoring nearby groundwater levels online you may be able to detect potential problems early and implement water conservation strategies that may prevent your well from going dry.

DEALING WITH A LOW-YIELDING WELL

What Is Well Yield?

Private wells are frequently drilled in rural areas to supply water to individual homes or farms. The maximum rate in gallons per minute (gpm) that a well can be pumped without lowering the water level in the borehole below the pump intake is called the *well yield*. Low-yielding wells are generally considered wells that cannot meet the peak water demand for the home or farm. The information below describes several steps that can be used to increase the adequacy of a low-yielding well.

Peak Demand

Dealing with low-yielding wells requires an understanding of *peak demand*. A well that yields only 1 gpm of water can still produce 1,440 gallons of water in a day. However, water use in a home or farm does not occur evenly during the day. There are peak usage times, typically during the morning and/or evening, when water demand is very high. These *peak demand* periods usually last from 30 minutes to 2 hours. An adequate water system must yield enough water to satisfy a peak demand for at least 2 hours.

Let's look at an example of how a low-yielding well can fail to meet peak demand. A family of four lives in a home with a well that yields about 1 gpm. On a typical Saturday morning, there may be a 2-hour peak demand period where water is used for multiple loads of laundry, breakfast dishes, showers, toilets, and sinks. Without water-saving appliances and fixtures, the water use during this 2-hour period could exceed 300 gallons. A 1-gpm well could only provide 120 gallons of water during this peak demand period, far short of what is needed.

Ideally, peak demand is determined for the home or farm before the well is drilled. That way the well and water system can be designed to meet the peak demand. For more information on estimating your water needs, refer to Chapter 2.

So what can be done if an existing well is not meeting peak water demand? The options generally fall into two categories: reducing peak water use or increasing storage within the water system.

1. Reducing Peak Water Use

Peak water demands on the well can be reduced by changing the timing of water-using activities or by reducing the amount of water used. Examples of changing the timing of water use include spreading laundry loads throughout the week instead of doing all loads in one day, and having some family members shower at night rather than all showering in the morning.

Reducing the amount of water used involves conserving water. This might include changes in water-use behaviors such as taking shorter showers or not washing the car. Changing water-use behavior to spread out peak water use may be inconvenient at times, but there is no added cost. A more permanent but costly water conservation solution is to install water-saving devices like front-loading clothes washers or low-flush toilets. Using a front-loading washer alone saves more than 20 gallons of water for each load of laundry.

Research has shown that installing water-saving devices and appliances can reduce household water use by up to 30 percent and save hundreds of dollars per year in energy used for heating water. Examples of typical water savings from various appliances and fixtures are given in the next section. The initial cost to retrofit the home with all of these water-saving devices could conservatively cost between $1,500 and $2,000.

2. Increasing Water Storage

Inadequacies in the well water yield can also be compensated for by increasing the amount of water stored within the water system. Added storage can be achieved in a pressure tank, a large storage tank (intermediate storage), or in the drilled borehole.

Pressure Tank Storage

The pressure tank allows a water system to operate automatically. It is, in a sense, a storage tank—but it has very limited storage capacity. Its primary purpose is to create and maintain pressure on the water in the pipeline.

As water from the source is pumped into the tank, the air in the space above the water is compressed. When the pressure on the water's surface reaches about 40 pounds per square inch (psi), a pressure-activated switch stops the pump. When a faucet is opened, the air pressure forces the water out of the tank through the pipeline until the pressure drops to about 20 psi. Then the pressure regulator trips the switch and starts the pump, which forces an equal amount of water back into the pressurized tank.

About 20 percent of the capacity of the pressure tank is available for use. A 42-gallon tank discharges about 8 gallons before the pump starts (an 82-gallon tank—16 gallons; a 120-gallon tank—about 24 gallons). Thus, larger pressure tanks alone provide slightly larger amounts of stored water, but the increased storage is not enough to solve problems with a low-yielding well.

Intermediate Storage

An intermediate storage system is simply a storage reservoir that is added to receive water from the well to meet peak water demand on the home or farm. A typical system is shown in Figure 6.4.

Intermediate storage systems are based on the concept that many low-yielding wells can provide a constant but limited flow 24 hours per day without appreciable drawdown. In this case, a normal well pump may cause the water level to drop to a critical point during periods of high use, and the pump will not be able to obtain the water needed to replenish the pressure tank at the rate at which it is withdrawn.

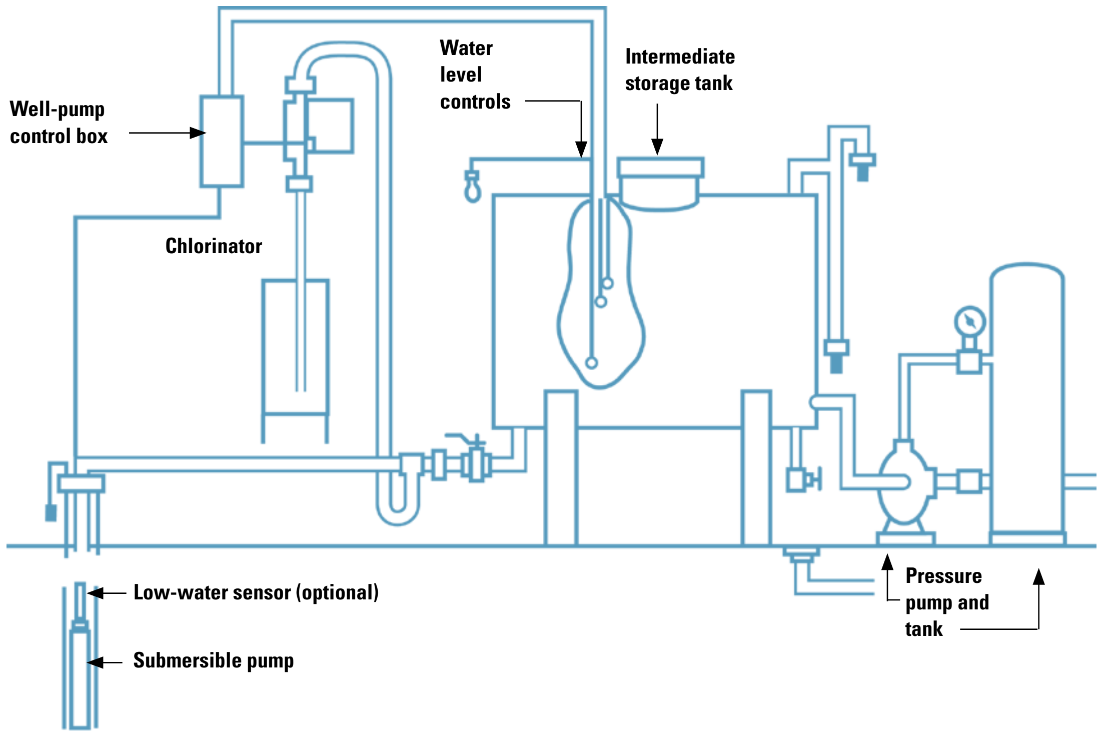
This problem can be solved by installing an intermediate storage reservoir between the well and the pressurized distribution system and limiting the pumping rate from the well. This reservoir then serves as the primary source of supply for the pressure pump. An intermediate storage water system requires two pumps and a large holding tank or reservoir at a rate that is compatible with the well's yield. The pump in the well pumps water into the reservoir; the pressure pump transfers the water from the reservoir to the pressure tank and into the distribution system. The intermediate storage tank is a nonpressurized tank or cistern, usually installed at about the same elevation of the building in which water is to be used. The depth of water stored in the nonpressurized storage reservoir is regulated either by a float switch or by a water-level sensor that controls the well pump's on-off operation.

Storage Tank Capacity

Many types of storage tanks can be installed to provide intermediate water storage. Most are made of plastic or concrete. In some instances, it may be desirable to install two intermediate storage tanks in parallel rather than one larger single unit. This arrangement provides some flexibility in that one tank can be removed from service for cleaning and maintenance while the other keeps the water system in operation.

For home water systems, the tank(s) must be protected from freezing by either burying them below the frost line or placing them in a heated garage or basement. Storage tank capacity for a residential home should be sized based on the number of people living in the house. Ideally, the storage tank(s) will hold enough water to meet a full day's water use. The tanks can then be slowly refilled overnight from the low-yielding well. As a rule of thumb, size the tank to allow for 100 gallons of water for every person in the home. Thus a family of five would need 500 gallons of storage in one or more tanks. Additional capacity should

Figure 6.4. Typical components of an intermediate storage system.



be provided if you foresee increased water demands in the future. A 300- to 500-gallon storage tank ranges from $250 to $500.

Intermediate storage tanks for farming operations are typically much larger and are sized based on the daily use of water for the farm. At a minimum, the storage tank(s) should be large enough to satisfy 2 hours of peak water use but, ideally, the tanks should be large enough to store water for an entire day. In addition, it would be wise to plan additional water storage for emergency use, such as fire protection. If the farm water use is unknown, it can be estimated using values from the section on estimating your water needs found in Chapter 2. The U.S. Department of Agriculture recommends a capacity of at least 2,000 gallons for an intermediate storage tank. Costs for large storage tanks vary from $500 (1,000 gallons) to $1,500 (3,000 gallons). Storage tanks for farm water should also be protected from freezing unless water use tends to be continuous enough to prevent freezing.

Whether they are used for home or farm water systems, intermediate storage tanks can also serve to aid in water treatment processes. If chlorine is used to disinfect the water supply, the storage tank may increase the water-chlorine contact time needed to destroy disease-producing bacteria and reduce the amount of chlorine required. The storage also serves as a treatment tank in which dissolved iron compounds oxidized by the chlorine are precipitated out of solution and settle to the bottom. Clear water remaining in the upper part of the tank is pumped into the pressure tank and distribution system.

Pressure Pump Capacity

A pressure pump is typically added after the intermediate storage tank(s) unless the system can be gravity fed to the home or barn. The pressure pump provides water to the pressure tank for distribution in the home or farm. Pressure pump capacity can be determined by estimating the total daily water requirement from the well (refer to the section on estimating your water needs in Chapter 2). Since most water is needed during a 2-hour period, the total daily water use should be divided by 2 hours and then by 60 minutes per hour to get the pump capacity in gallons per minute. For example, a single family home requiring 250 gallons of water per day (gpd) would need a pressure pump capacity of:

250 gpd / 2 hr / 60 min = 2.1 gpm

A farm well requiring 5,000 gpd would require a larger pressure pump capable of moving 42 gpm.

Well Pump Capacity

The well pump for an intermediate storage water system should have a rated pumping capacity slightly less than the yield of the well, or else a flow restrictor should be used. The pump should be expected to operate more or less continuously, if necessary, to keep the storage reservoir full. Normally, a low-water cut-off switch controlled by water-level sensors in the well should be connected to a relay at the pump switch box. A low-water signal relayed to the main switch should override other pump controls and stop the pump if the water level drops to a critically low point where air or sediment would be pulled into the system.

A schematic arrangement for an entire intermediate water-storage system is shown in Figure 6.4. Note that this diagram includes a chlorinator between the well and the nonpressurized storage tank and water level sensors in the tank. A sensing device for a low-level water cut-off switch in the well should be installed to protect the well pump. The typical cost for a household intermediate storage system (without the chlorinator) would probably be less than $1,500, depending on the amount of labor. A larger farm intermediate storage system would be closer to $3,000, but it may be significantly more if very large amounts of water must be stored.

Borehole Storage

A final method for making better use of a low-yielding well is to increase the storage of water within the borehole. The borehole may be able to store several hundred gallons of water to meet peak water demand. Ideally, extra borehole storage is added to a low-yielding well when it is first drilled to meet the expected home or farm water demand (refer to the section on estimating your water needs in Chapter 2).

The amount of water stored in a well can be increased by widening or deepening the borehole. For example, a typical 6-inch-diameter well with 100 feet of water in the borehole stores 147 gallons of water. If the 6-inch well were replaced with a 10-inch-diameter well, the storage would increase dramatically to 408 gallons of water. The additional 261 gallons of stored water may be sufficient to serve a single family home even if the well yield is very low.

Increasing diameter alone should not change the water-quality conditions from the well since it still draws water from the same aquifer. However, increasing diameter alone is risky because its success depends on a relatively constant depth of water in the well. In reality, the depth of water in the well may vary dramatically during wet and dry periods, causing the change in storage to also vary considerably. For example, a well that typically has 100 feet of water may have less than 20 feet of water storage during a drought. As a result, increasing the diameter of this well from 6 inches to 10 inches would only increase the water storage by about 50 gallons during a drought—far less than would be needed to meet peak water demand.

In wells where the water level changes significantly during dry periods, deepening the well may be a better alternative to increase borehole storage. Drilling an existing 6-inch-diameter well 100 feet deeper would increase the water storage by 147 gallons. However, there can be significant changes in water quality as you deepen an existing well. The deeper well may access groundwater with natural or human-made pollutants that may require the addition of water-treatment equipment. Consulting a local, experienced well driller and nearby well owners can be helpful in determining the risk of drilling an existing well into deeper groundwater.

Cost is an obvious consideration when increasing the diameter or depth of an existing well. Well components like the pump, wiring, conduit, and casing need to be removed before the existing well can be redrilled. Further costs are based on a per-foot drilling cost from the contractor. Some drillers may prefer simply to drill a new well to the new specifications rather than alter the existing well.

A Final Word

A low-yielding well does not have to be a source of persistent concern for a homeowner or farmer. The methods described in this guide can often be used to make these wells meet peak water demands. Simple changes in water-use habits may be enough to meet peak water demands where water shortages occur infrequently. If larger water savings are needed, water-saving devices and appliances offer large water savings and easy installation for moderate costs. More serious cases, where water availability routinely fails to meet peak water demand, warrant installation of an intermediate storage system. A local water well contractor can provide guidance and a cost estimate to increase borehole storage.

WATER CONSERVATION FOR THE HOMEOWNER

Keeping an adequate supply of high-quality water flowing from taps and disposing of wastewater requires considerable effort and expense. The less we use, the less effort and expense is required to supply us with water. The smaller the volume of wastewater produced, the less it costs to treat it. Where sewage treatment plants are already overloaded, this reduction would lessen pollution by improving waste treatment. Less energy use also means reduced air pollution and lower water-heating bills. With today's high costs for water, sewer service, and energy, conservation through efficient plumbing fixtures and appliances can result in significant homeowner savings.

Water-Efficient Plumbing Fixtures

Gravity-Flush Toilets

Water-efficient toilets have evolved over the past 30 years, with much of the pioneering work occurring in the early 1970s. Many innovations have been introduced, including toilets with two flush volumes (one for liquid and one for solid wastes) and models that incorporate water pressure in the service line to flush. The ultra-lowflush models of today retain the basic design of the gravity-flush toilet. They look like conventional models but use 1.6 gallons of water per flush versus the 3–5 gallons of older models.

These low-flush toilets are required in new construction. Congress recently commissioned a review of low-flush toilets by the General Accounting Office (GAO) in response to efforts by some officials to repeal federal requirements. The GAO report concluded that homes with these toilets used 40 percent less water for flushing, and requirements for these and other water-efficient fixtures were "effective in saving water." This unbiased, nonpartisan review firmly established this toilet's place in conserving water resources.

Replacing conventional 4-gallon-per-flush (gpf) toilets with 1.6 gpf toilets throughout your home will save approximately 12 gallons of water per day per person, which translates into over 4,000 gallons each year (see Table 6.3).

Air-Assisted Toilets

Photo courtesy of Microphor Corporation, Willits, California.

Air-assisted toilets, which require compressed air for waste removal, have been used for many years where minimal water use or waste flow reduction is at a premium. Highway rest-stop facilities are a prime example. Use of these toilets in homes is less widespread because of the need for air lines, a compressor, and the higher initial costs of air-assisted units. However, domestic use of air-assisted toilets at present water and sewer rates can be cost effective. Increased education and marketing efforts may result in wider adoption of these highly efficient toilets.

Water use per flush is only 0.5 gallons, roughly one-third the volume of low-flush toilets. With proper maintenance, air-assisted models remain serviceable for many years and more than return their significantly higher costs.

Table 6.3. Estimated water and energy savings from various water-saving fixtures.

	Frequency of use (per person)	Daily water use without water conservation device (gal/ person)*	Daily water use with water-saving devices (gal/ person)	Daily water savings with water-saving devices (gal/ person)	Annual water savings (gal/ perso)	Estimated annual energy savings of kilowatt-hours (per person)
Low-flush toilet (1.6 gpf)	5.1 flushes/day	20.4	8.2	12.2	4,453	0
Low-volume showerhead (2.5 gpm)	5.3 minutes/day	15.9	13.3	2.6	949	123
Low-volume faucet (rated flow 1.5 gpm)	4 minutes/day	12	6	6	2,190	125
Front-loading washing machine (27/gpl)	0.37 loads/day	18.9	10	8.9	3,249	316
Water-efficient dishwasher (7.0 gpl)	0.1 loads/day	1.1	0.7	0.4	146	36
Total		68.3	38.2	30.1	10,987	600

*Assumes conventional toilets at 4 gpf, showerheads at 3 gpm, faucets at 3 gpm, washing machine at 51 gpl, and dishwasher at 11 gpl.

Source: Adapted from Vickers, A. 2001. *Handbook of water use and conservation.* WaterPlow Press, Amherst, MA.

Installing air-assisted toilets is more involved, but not difficult. A small, 1/4-horsepower compressor, with an air line to each toilet, must be located in your home's garage, basement, or utility closet. Approximately 20 flushes may be made before the compressor cycles on; noise is not usually an issue. More than one toilet can be operated with the same compressor.

Composting Toilets

Photo courtesy of Allen White, Bio-Sun Systems, Inc., Millerton, Pa.

Interest in composting toilets has continued for several decades. These toilets use no water and rely on a mixture of human waste and other compostable organic matter. Proper maintenance is required to maintain aerobic decomposition and prevent odors.

Composting toilets are expensive and difficult to retrofit. They require a commitment to management and must be tended to ensure proper operation. Most on-lot sewage management jurisdictions do not relax permit requirements concerning composting toilets because the gray water portion of wastewater must be accommodated by a conventional treatment system. However, in the right situation, they may be valuable residential water-conservation tools.

Showerheads

Conventional showerheads typically deliver 3–8 gallons of water per minute (gpm). Conservation is accomplished by restricting water's flow rate through the showerhead. Showerheads with reduced flows as low as 2 gpm, at normal household water pressure, have been designed to give an acceptable shower and reduce water use. They can be sensitive to low water pressure and sudden changes in temperature; consequently, proper pressure-balanced mixing valves are necessary. Exiting water temperatures normally need to be slightly higher because the smaller droplets cool quickly. Slightly hotter water does not negate the substantial energy savings achieved by low-flow showerheads. Replacing conventional 3 gpm showerheads with the low-volume, 2.5 gpm models would save approximately 1,000 gallons of water per year per person in your home (Table 6.3).

Faucets

Most faucets deliver 3–7 gallons of water per minute. As is true of showerheads, restricting a faucet's flow rate can save water. Where faucets are operated continuously, as in washing operations, significant savings are possible. Residential, low-volume faucets typically produce 1.5–2.5 gpm. In institutional settings, flow-restricted faucets with spray heads that turn off automatically are increasingly used. When combined with point-of-use water heating, significant energy savings are possible in addition to reduced water use. Maintenance is required to prevent water loss from malfunctioning units. Replacing typical 3 gpm faucets with 1.5 gpm models would save approximately 2,000 gallons of water per year per person in your home.

Automatic Clothes Washers

Conventional, top-loading clothes washers use about 40–50 gallons of water per load (gpl). Great strides have recently been made to improve the reliability and ease of front-loading automatic clothes washers, which use less water and energy. Durability was previously an issue, especially with regard to significantly increased costs. However, newer models have resolved this issue. Front loaders are more efficient and wash with much less water and detergent. The tumbling action of the laundry reduces water requirements for equivalent load sizes and cleanliness. Possible savings are shown in Table 6.3. The reduction in hot water use saves significant energy.

Automatic Dishwashers

Automatic dishwashers have relieved us of this unpleasant mealtime chore, but they use large amounts of water. If dishwashers are fully loaded for each use, water can be saved. Newer, more efficient models may use as little as 4.5 gpl. However, units that are competitively priced use 6–7 gpl. Automatic dishwashers save water, as well as energy, by limiting hot water use. Potential savings are shown in Table 6.3. Water and energy savings quickly repay the higher cost of these machines.

Saving Money

Reducing domestic, indoor water use saves money in two ways. Homes using public supplies typically pay for each gallon delivered to them. The average cost for this water is about $5 for each 1,000 gallons, or about half a penny per gallon. As illustrated in Table 6.3, installing water-saving devices can save about 11,000 gallons of water per person per year, which translates into about $220 per year for a family of four.

Devices that reduce hot water use (such as efficient clothes washers, dishwashers, faucets, and showerheads) also save money because they consume less energy. These savings, in kilowatt-hours per person, are shown in Table 6.3. Installing these appliances could save about 600 kilowatt-hours of electricity per person annually in your home. Assuming an average energy cost of about $0.08 per kilowatt hour, this conservation translates into about $200 per year for a family of four!

Outdoor Water Conservation

Although outdoor water use is small compared to indoor uses in Pennsylvania, opportunities to save water still exist, especially during periods of dry weather when they may be most critical. Outdoor conservation is especially important since a much larger percentage of water is lost through evaporation.

Since most water outside is used to water plants, landscaping with drought-tolerant (called xeriscaping) and native plants can greatly reduce consumption. Studies in the western United States have found that residential, xeriscaped lawns use half as much water as traditional landscapes. Using mulch around outdoor plants also helps to trap moisture and reduce watering. Efficient drip irrigation systems, rather than conventional sprinklers, can produce water savings of 25–75 percent. Proper irrigation scheduling can reduce water used on lawns. This outdoor watering should be done only in the early morning (before 8 a.m.) or in the evening after sunset to minimize loss from evaporation. Ten to fifteen minutes of watering is usually enough to saturate most soils.

Rainwater harvesting, or using rain barrels, is a simple way to conserve water outdoors. Rainwater harvesting can be accomplished by placing a plastic container (such as a heavy-duty garbage can) under a downspout to collect water running off the roof. The rain collection container should be tightly covered to prevent mosquitoes from laying eggs and small animals from being trapped inside.

Summary—Why Conserve?

Installing water-efficient plumbing fixtures and appliances contributes to conserving water and energy and reducing wastewater flows. Where on-lot (septic tank) sewage disposal systems are used, reduced water use improves treatment efficiency and reduces the possibility that the system will fail. Benefits include reduced utility bills for homeowners; deferred capital expenditures for system expansions for the utilities providing water, energy, and sewer services; and a cleaner, higher-quality environment for all.

Appendix A—Relevant Web Sites and Contact Information

American Ground Water Trust: www.agwt.org/index.htm

National Ground Water Association: www.ngwa.org/

National Ground Water Association (well owner Website): www.wellowner.org

Pennsylvania Department of Environmental Protection Private Well Homepage: www.depweb.state.pa.us (keyword: private wells)

Pennsylvania Department of Environmental Protection regional offices:

Northeast office: **570-826-2511**

Southeast office: **484-250-5900**

Northcentral office: **570-327-3636**

Southcentral office: **717-705-4741**

Northwest office: **814-332-6945**

Southwest office: **412-442-4000**

Pennsylvania Ground Water Association: www.pgwa.org/

Pennsylvania Ground Water Online (Department of Conservation and Natural Resources): www.dcnr.state.pa.us/topogeo/ ground water/

Pennsylvania Master Well Owner Network: mwon.cas.psu.edu/

Penn State Water Resources Extension: water.cas.psu.edu/

Pennsylvania Geologic Survey, Department of Conservation and Natural Resources: 717-702-2073

USGS Water Resources of Pennsylvania: pa.water.usgs.gov/

Appendix B—Glossary of Common Terms and Abbreviations

Acid mine drainage—Drainage of water from areas that have been mined for coal or other mineral ores; the water has a low pH, sometimes less than 2.0 because of its contact with sulfur-bearing minerals, and often contains metals in concentrations toxic to aquatic life.

Acidity—Total amount of acid and acid-forming substances in water; any substance that has a pH level below 7.

Action level—The level of any contaminant which, if exceeded, triggers treatment or other requirements that a public water system must follow.

Acute health effect—An immediate effect that may result from exposure to certain drinking water contaminants.

Aesthetic—Related to or dealing with the way something looks.

Alkaline—The condition of water or soil containing a sufficient amount of alkali substances to raise the pH above 7.0.

Aquifer—Saturated layer of sand, gravel, or rock that can readily transmit water.

Aquitards—Geologic formations made up of layers of either clay with tiny, poorly connected pores or nonporous rock; these formations restrict the flow of water from one aquifer to another.

Artesian well—Well water under pressure because of being drilled into a confined aquifer. (See also Flowing Artesian Well.) The water level in the well rises above the level of the aquifer.

Atmosphere—The whole mass of air surrounding the earth.

Background level—The average presence of a substance in the environment or occurring naturally.

Bacteria—Microscopic living organisms usually consisting of a single cell. Some bacteria in soil, water, or air may cause human, animal, and plant health problems.

Base flow—Water in a stream provided by groundwater seeping through stream banks and stream beds. Groundwater that discharges to surface water.

Borehole—A hole drilled into the subsurface.

Brine—Salty groundwater. Water of a sea or salt lake.

Calcium carbonate—A compound consisting of the elements calcium, carbon, and oxygen. Its chemical formula is $CaCO_3$. It is somewhat soluble in water. Spelunkers (cave explorers) like it because water can remove it to make a cave and rearrange it, making stalagmites and stalactites to look at. Boiler operators and cooks dislike it because it precipitates out of hot water, making stonelike deposits that are hard to remove.

Calcium carbonate ($CaCO_3$) equivalent—An expression of the concentration of specified constituents in water, in terms of their equivalent value to calcium carbonate. For example, the hardness in water caused by calcium, magnesium, and other ions is usually described as calcium carbonate equivalent.

Carcinogen—Any substance that produces cancer in an organism.

Central nervous system (CNS)—Portion of the nervous system consisting of the brain and spinal cord.

Chronic health effect—The possible result of exposure over many years to a drinking water contaminant at levels above its maximum contaminant level (MCL).

Cistern—A storage facility used for storing water for a home or farm. Often used to store rain water.

Coliform—A group of bacteria found in the intestines of warm-blooded animals (including humans) and in plants, soil, air, and water. Fecal coliforms are a specific class of bacteria that inhabit only the intestines of warm-blooded animals. The presence of coliform is an indication that the water is polluted and may contain disease-causing organisms.

Concentration—A measurement of the amount of a substance contained in a liter of water. Usually expressed as mg/L.

Conductivity—A measure of water's ability to carry an electric current. Related to the total dissolved solids (TDS) in the water.

Cone of depression—A cone shape in the water table where it has been lowered around a well due to pumping of the well.

Confined aquifer—A saturated layer of sand, gravel, or rock that has clay or nonporous rock above and below it.

Consumptive water use—Water that is used and then not returned to its source. Evaporation, transpiration, and bottled water are examples of consumptive use.

Contaminant—Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

Corrosive—The ability of water to remove substances by chemical or electrolytic activity over time, such as water pipes in a home.

***Cryptosporidium parvum*—**Flagellate protozoan that is shed during its oocyst stage with the feces of people and animals. When water containing these oocysts is ingested, the protozoan causes a severe gastrointestinal disease.

Diameter—The length of a straight line through the center of a round object. The width of a circular or cylindrical object, such as the opening of a well.

Dolomite—A mineral consisting of a calcium and magnesium carbonate found in crystals and in extensive beds as a compact limestone.

Effluent—Waste material discharged into the environment.

EPA—The U.S. Environmental Protection Agency.

Evaporation—To pass off in vapor or invisible minute particles. The physical process by which a liquid is transferred into a gaseous state. The conversion of liquid water to water vapor.

Evapotranspiration—Loss of water from the soil by evaporation and transpiration from plants.

Exposure—Contact with a chemical or physical agent.

FDA—The Federal Food and Drug Administration.

Fecal coliform bacteria—Bacteria found in the intestinal tracts of animals. Their presence in water is an indicator of pollution and possible contamination by pathogens.

Filtration—A process for removing particulate matter from water by passage through porous media.

First draw—The water that immediately comes out when a faucet is first opened after having been unused for a significant period of time. This water is likely to have the highest levels of lead and copper contamination from plumbing materials.

Flowing artesian well—Well water under enough pressure to flow onto the land surface without being pumped.

Foliated—Composed of or separable into layers.

Gastroenteritis—An inflammation of the stomach and intestine resulting in diarrhea, with vomiting and cramps when irritation is excessive. When caused by an infectious agent, it is often associated with fever.

Geologic—Related to the study of the earth.

***Giardia lamblia*—**Flagellate protozoan that is shed during its oocyst stage with the feces of people and animals. When water containing these oocysts is ingested, the protozoan causes a severe gastrointestinal disease called *giardiasis*.

GPM—Gallons per minute. A common unit used to express the flow of water over time.

Grain per gallon (gpg)—A unit of measure for hardness, equal to 17.1 mg/L.

Gram (g)—A unit of mass (weight) equivalent to one milliliter of water at 4 degrees Celsius. 1/454 of a pound.

Granular activated carbon (GAC)—Material used in water treatment devices to remove organic chemicals, radon, and other pollutants.

Groundwater—Water found below the ground surface and located below the water table. Also known as the "saturated zone" because all the soil pores and rock fractures are completely filled with water. The source of water is springs and wells.

Groundwater mining—Extracting groundwater faster than it is being recharged.

Gross alpha particle activity—The total radioactivity due to alpha particle emission, as inferred from measurements on a dry sample. Alpha particles do not penetrate solid materials.

Gross beta particle activity—The total radioactivity due to beta particle emission, as inferred from measurements on a dry sample. Beta particles penetrate solid materials and are more hazardous.

Hard water—Alkaline water containing dissolved salts that interfere with some industrial processes and prevent soap from lathering. Some textbooks define hard water as water with a hardness of more than 100 mg/L (as calcium carbonate).

Hardness—The presence of dissolved substances, chiefly calcium carbonate, in water. Noted by the greater amount of soap needed to produce lather and the deposits of calcium carbonate that form on heated surfaces, limiting their ability to transfer heat.

Heavy metals—Metallic elements with high atomic weights; e.g., mercury, chromium, cadmium, arsenic, and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Heterotrophic plate count (HPC)—A measure of the total number of bacteria in a sample. Also known as the *standard plate count* (SPC).

Hydrologic—Dealing with the properties, distribution, and circulation of water on the land surface, in the soil and underlying rock, and in the atmosphere.

Impervious—Not allowing entrance or passage. Impervious surfaces may include paved parking lots, buildings, etc., that cause precipitation to run off as surface water rather than percolate and infiltrate the ground.

Infiltrate—To pass into or through a substance, such as when water seeps into the soil.

Inorganic chemicals (IOCs)—Chemicals of mineral origin.

Limestone—A rock formed chiefly by the accumulation of organic remains of marine fauna, consisting mainly of calcium carbonate.

MCL (maximum contaminant level)—The greatest level of contaminants of certain chemicals allowed in public drinking water.

Microgram (µg)—One-millionth of a gram.

Micrograms per liter (µg/L)—One microgram of a substance dissolved in each liter of water. This unit is equal to parts per billion (ppb).

Microorganisms—Living organisms that can be seen individually only with the aid of a microscope.

Milligram (mg)—One-thousandth of a gram.

Milligrams per liter (mg/L)—A measure of concentration of a dissolved substance. A concentration of one mg/L means that one milligram of a substance is dissolved in each liter of water. For practical purposes, this unit is equal to parts per million (ppm).

Most probable number (MPN)—MPN is the *most probable number* of coliform group organisms per unit volume of sample water as determined by a statistical relationship. Expressed as the number of organisms per 100 ml of sample water.

ND—Abbreviation for "not detected." Laboratory expression for a concentration of a substance in water too small to be detected by the instrumentation used.

Nonconsumptive water use—Water that is used and then returned to its source, such as in hydroelectric power generation where water turns the turbines and then is returned to its source.

Nonpotable—Water that may contain objectionable pollution, contamination, minerals, or infective agents and considered unsafe and/or unpalatable for drinking.

Nonvolatile organic chemicals—Organic chemicals that do not escape readily into air from water. Also known as *synthetic organic chemicals* (SOCs).

National Sanitation Foundation (NSF)—Independent testing organization for water treatment equipment.

Nephelometric turbidity unit (NTU)—Unit of measure for turbidity in water.

Organics—A term used to refer to chemical compounds made from carbon molecules.

Oxidized—To combine with oxygen in order to break down organic waste or chemicals in water or sewage by bacterial and chemical means. Iron after combination with oxygen is called rust.

Parts per billion (ppb)—Parts of pollutant per billion parts of water a measurement of concentration on a weight or volume basis. This term is equivalent to micrograms per liter (µg/L).

Parts per million (ppm)—Parts of pollutant per million parts of water, a measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/L).

Pathogens—Microorganisms that can cause disease in other organisms or in humans, animals, and plants. They may be bacteria, viruses, or parasites found in sewage or runoff from animal farms or rural areas populated with domestic and/or wild animals.

Peak demand—Highest volume of water needed during a defined time period.

Pesticide—Any substance or chemical designed or formulated to kill or control weeds or animal pests.

pH (percent hydrogen)—Values range from 1 to 14. Water with a pH of 7 is neutral, below 7 is acidic, and above 7 is basic (usually alkaline). Used to express acidity or alkalinity of a solution in terms of the hydrogen concentration.

Percloroethylene (PCE)—A colorless nonflammable liquid often used as a solvent in dry cleaning and for removal of grease from metals.

Percolating—To trickle through a permeable material such as soil.

Picocurie per liter (pCi/L)—A measure of radioactivity in water, commonly used for radon. One picocurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second as measured by a Geiger counter.

POE (point of entry)—Describes the location of a device that treats water to the entire house.

Potable water—Water considered safe to drink.

POU (point of use)—Describes the location of a device that treats water at a particular tap.

Precipitation—Rain, snow, sleet, or hail.

Pressure tank—Tank that holds a volume of water under pressure to supply water to a system when the well pump is not running.

Primary drinking water standard—See Maximum Contaminant Level (MCL).

Public water system—A system for providing piped water for human consumption to the public, having at least 15 service connections or regularly providing water at least 60 days out of the year to 25 or more people per day. A public water system is either a *community water system* (town) or a *noncommunity water system* (gas station, camp, etc.).

Recharge—Water that enters the soil surface, trickles downward by gravity, and becomes groundwater.

Recommended maximum contaminant level (RMCL)—See Secondary Maximum Contaminant Level below.

Reservoir—A human-made lake where water is collected and stored in quantity for use.

Retrofit—To furnish with new parts or equipment not available when manufactured.

Secondary drinking water standard—See Secondary Maximum Contaminant Level (SMCL).

Secondary maximum contaminant level (SMCL)—Limits or standards given to pollutants that have only aesthetic effects in water. Also called *recommended maximum contaminant levels,* or RMCLs.

Seeps—A location where water contained in the ground oozes slowly to the surface and often forms a pool.

Septic system—An onsite system designed to treat and dispose of domestic sewage.

Soft water—Water having a low concentration of calcium and magnesium ions. According to U.S. Geological Survey guidelines, soft water is water having a hardness of 60 milligrams per liter or less.

Spring—A location where the water table or groundwater reaches the surface of the ground and results in a significant flow of water.

Standard plate count (SPC)—See Heterotrophic Plate Count (HPC) above.

Surface water—All water naturally open to the atmosphere, and all springs, wells, or other collectors that are directly influenced by surface water.

Synthetic organic chemicals (SOC)—Term used to describe nonvolatile organic chemicals such as most pesticides.

TNTC—Abbreviation for “too numerous to count.” A measure of bacterial concentration.

Total dissolved solids (TDS)—A measure of all of the dissolved ions in water.

Transpiration—The passing of water through a vegetative plant and back to the atmosphere.

Trichloroethylene (TCE)—A nonflammable liquid often used as a solvent in dry cleaning and for removal of grease from metals.

Turbidity—The cloudy appearance of water caused by the presence of suspended and colloidal matter. Used to indicate the clarity of water.

Unconfined aquifer—A saturated layer of sand, gravel, or rock that has no aquitard above it. Also known as a water table aquifer.

USGS—The U.S. Geological Survey.

Virus—The smallest form of microorganism capable of causing disease.

Volatile organic chemicals (VOCs)—Organic chemicals that escape readily into the air from water.

Watershed—An area of land that drains downslope to the lowest point such as a river, lake, stream, or groundwater.

Water table—The upper surface of the saturated zone or groundwater.

Well—A deep hole or shaft sunk into the earth to obtain water, oil, gas, or brine.

Well decommissioning—The process of properly sealing an unused well to prevent groundwater pollution.

Well head protection—Limiting or eliminating the use of potentially contaminating substances within the watershed area for the well. The watershed area is difficult to establish exactly. Instead, a circular area is used. The area is centered around the well with a diameter proportional to the average daily volume of water extracted from the well. This diameter should be a minimum of 100 feet for a household well.

Appendix C—Important Information and References

CHAPTER 1

Groundwater Basics

Publication of this material was supported, in part, with funding from the Pennsylvania Water Resources Research Center made possible by the U.S. Geological Survey through the Water Resources Research Act of 1964.

Based on *A Quick Look at Pennsylvania Groundwater* by Joe Makuch, Department of Agricultural Engineering, The Pennsylvania State University; and Janice R. Ward, Water Resources Division, U.S. Geological Survey. The Pennsylvania State University and the U.S. Geological Survey Cooperating, 1986.

Publications for Additional Reading

Citizens' Guide to Groundwater Protection. Washington, D.C.: U.S. Environmental Protection Agency Office of Water, 1990.

The Geology of Pennsylvania's Groundwater by G. M. Fleeger. 3rd ed. Educational Series 3. Harrisburg: Pennsylvania Geological Survey, 1999.

Groundwater Protection and Management in Pennsylvania: An Introductory Guide for Citizens and Local Officials. 3rd ed. Washington, D.C.: League of Women Voters, 2001.

Pennsylvania Groundwater Quality. U.S. Geological Survey Water Supply Paper 2325, National Water Summary. Reston, Va.: U.S. Geological Survey, 1986.

Protecting Your Groundwater. Educating for Action. League of Women Voters Education Fund, Pub. No. 180. Washington, D.C.: League of Women Voters, 1994.

CHAPTER 2

Water System Planning—Estimating Water Needs

Sources of Water Use Estimates

1. *Planning Guide for Water Consumption*. 1981. Agricultural and Biological Engineering Fact Sheet SW-1. Penn State Cooperative Extension.

2. *Private Water Systems Handbook*. 1992. Midwest Plan Service. MWPS-14.

3. *Handbook of Water Use and Conservation*. 2001. Water-Plow Press. Amherst, MA.

4. *Consumptive Water Use Restrictions in the Delaware River*

Basin. 2002. Agricultural and Biological Engineering Fact Sheet F-199, Penn State Cooperative Extension.

5. *Guideline for Milking Center Wastewater.* 1998. Natural Resource, Agriculture, and Engineering Service. NRAES-115.

Dealing with Unused Wells

Well-decommissioning procedures based on the recommendations of the National Ground Water Association, www.ngwa.org

Smith, Stuart. 1998. *Manual of Water Well Construction Practices.* Westerville, Ohio: National Ground Water Association Press.

Spring Development and Protection

Images adapted from *Safeguarding Wells and Springs from Bacterial Contamination,* 1996, Department of Agricultural and Biological Engineering, The Pennsylvania State University.

Rainwater Cisterns

Contribution No. 173, "Feasibility of Rainwater Collection Systems in California" by David Jenkins and Frank Pearson. Available from California Water Resources Center, University of California, 475 Kerr Hall, Davis, California 95616.

Customer information brochure, Water Filtration Co., 108B Industry Road, Marietta, Ohio 45750.

Private Water Systems Handbook, 1979. Publication MWPS-14, Midwest Plan Service, Iowa State University, Ames, Iowa 50010, attn. Extension Agricultural Engineer.

CHAPTER 3

Sharpe, W. E., Mooney, D. W., and Adams, R. S. 1985. "An Analysis of Groundwater Quality Data Obtained from Private Individual Water Systems in Pennsylvania." *Northeastern Environmental Science*, 4(3-4), 155-59.

Swistock, B. R., Sharpe, W. E., and Robillard, P. D. 1993. "A Survey of Lead, Nitrate and Radon Contamination of Private Individual Water Systems In Pennsylvania." *Journal of Environmental Health*, 55(5), 6-12.

Swistock, B. R., S. Clemens, and W. E. Sharpe. 2009. Drinking water quality in rural Pennsylvania and the effect of management practices. Final report, The Center for Rural Pennsylvania, Harrisburg, PA, for Cooperative Agreements 2006-7 and 2007-10. Available online at www.ruralpa.org.

Roadside Dumps and Water Quality

Christensen, T. H., R. Cossu, and R. Stegmann. 1992. *Landfilling of Waste: Leachate.* New York: Elsevier Applied Science.

Closz, J., P. Gill, D. Lane, and E. Long. 1995. *Is Illegal Dumping a Problem in Huntingdon County?* Huntingdon Area School District Senior Humanities Project.

Izzo, Becky. 2002. *Project Trash: Learning about Littering and Illegal Dumping.* Greensburg: PA CleanWays.

Peavy, Howard, D. R. Rowe, and G. Tchobanoglous. 1985. *Environmental Engineering.* New York: McGraw-Hill.

Pennsylvania Bulletin, Volume 22, Number 27, July 4, 1992.

Pennsylvania Code, Title 25, Chapters 271–85. Commonwealth of Pennsylvania. Current through 32 Pa. B. 2572 (May 18, 2002).

Pennsylvania Code, Title 25, Chapters 260–70. Commonwealth of Pennsylvania. Amended through January 16, 1993.

Pennsylvania Code, Title 25, Chapters 75, 101, 271, 273, 277, 279, 281, 283, 287–89, 293, 295, 297, and 299. Commonwealth of Pennsylvania. Current through July 4, 1992.

Qasim, Syed R., and Walter Chiang. 1994. *Sanitary Landfill Leachate: Generation, Control and Treatment.* Lancaster, Pa.: Technomic.

Swistock, Bryan, W. E. Sharpe, and J. Clark. 2003. *Water Tests: What Do the Numbers Mean?* University Park, Pa.: The Pennsylvania State University.

Tammemagi, Hans. 1999. *The Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future.* New York: Oxford University Press.

Unknown. 1998. *Illegal Dumping Prevention Guidebook.* Chicago, Ill.: U.S. Environmental Protection Agency Region 5, Waste, Pesticides, and Toxics Division.

Unknown. 1998. *Safe Drinking Water Program Summary of Key Requirements for Community Water Systems.* Commonwealth of Pennsylvania, Department of Environmental Protection, Bureau of Water Supply Management.

U.S. Environmental Protection Agency. 2004. *2004 Edition of the Drinking Water Standards and Health Advisories.* Washington, D.C.: EPA Office of Water.

Westlake, Kenneth. 1995. *Landfill Waste Pollution and Control.* Chichester: Albion.

Gas Well Drilling

Clark, J., B. R. Swistock, and S. Clemens. 2007. Unpublished data collected from 200 private water wells in McKean County.

Gough, W. R., and B. A. Waite. 1990. "Oil and Gas Exploration and Water Quality Considerations," Chapter 29 in: *Water Resources in Pennsylvania: Availability, Quality and Management.* Edited by S. K. Majumdar, E. W. Miller, and R. R. Parizek. The Pennsylvania Academy of Science. pp. 384-98.

DeWalle, D. R., and and D. G. Galeone. 1990. "One-Time Dormant Season Application of Gas Well Brine on Forest Land." *Journal of Environmental Quality*, 19:288-95.

Pennsylvania Department of Environmental Protection, 2007. "Oil and Gas Well Drilling and Production in Pennsylvania." DEP Fact Sheet 2018, 3 pp.

CHAPTER 4

Swistock, B. R., S. Clemens, and W. E. Sharpe. 2009. Drinking water quality in rural Pennsylvania and the effect of management practices. Final report, The Center for Rural Pennsylvania, Harrisburg, PA, for Cooperative Agreements 2006-7 and 2007-10. Available online at www.ruralpa.org.

Zogorski, J. S., J. M. Carter, T. Ivahnenko, W. W. Lapham, M. J. Moran, B. L. Rowe, P. J. Squillace, and P. L. Toccalino. 2006. *Volatile Organic Compounds in the Nation's Ground Water and Drinking-Water Supply Wells,* USGS Circular 1292.

CHAPTER 5

Alleman, J. E. 1985. "A Performance Evaluation For Magnetic Water Treatment." Fourth Domestic Water Quality Symposium. ASAE and Water Quality Association, 16 November.

Duffy, E. A. 1977. Investigation of Magnetic Water Treatment Devices. Doctoral Thesis. Clemson University.

Gruber, C. E., and D. D. Carda. 1981. "Measurable Parameters in Water Conditioning Equipment as Determined in Laboratory Simulations at Rapid City, South Dakota." Final report issued to the Water Quality Association. South Dakota School of Mines and Technology.

Iowa Judgment on Electromagnetic Water Conditioning Device. Water Quality Association release. Mitchell, H. 1987. "Magnetic 'Water Softener' Found to Be the Stuff of Legend, Not Fact." *The Toronto Star.* September 19.

Nowlin, D. D. 1983. Magnetic Water Treatment Facts and Fallacies. American Society of Agricultural Engineers, Winter Meetings, 1983.

Swistock, B. R., S. Clemens, and W. E. Sharpe. 2009. Drinking water quality in rural Pennsylvania and the effect of management practices. Final report, The Center for Rural Pennsylvania, Harrisburg, PA, for Cooperative Agreements 2006-7 and 2007-10. Available online at www.ruralpa.org.

CHAPTER 6

Hutson et al. 2000. *Estimated Use of Water in the United States in 2000.* U.S. Geological Survey, Circular 1268, Washington, D.C.

Swistock, B. R., and W. E. Sharpe. 2005. "Managing Your Well During A Drought." Penn State Cooperative Extension, Water Facts #7.

Water Conservation—How Much Water and Money Can You Save?

Water and energy use estimates in this fact sheet are based on information published in: Vickers, A. 2001. *Handbook of Water Use and Conservation.* WaterPlow Press, Amherst, MA.

APPENDIX B

"Arizona Know Your Water," University of Arizona, Artiola, Farrell-Poe and Moxley, 2006.

Websters Ninth New College Dictionary, Merriam-Webster, Inc., Springfield, MA. 1983.

Water Words Dictionary, Nevada Division of Water Resources, Department of Conservation and Natural Resources.

Visit Penn State's College of Agricultural Sciences on the Web: agsci.psu.edu

Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

This publication is available from the Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802. For information telephone 814-865-6713.

This publication is available in alternative media on request.

Produced by Ag Communications and Marketing

CODE # AGRS-111 1M809MPC 4954

Contents

Introduction

Over three million rural residents of Pennsylvania rely on a private water system (individual well, spring, or cistern) for their home water supply. These water supplies generally provide adequate and safe drinking water for rural homes that lie outside the area served by public water supplies. In addition, surveys of homeowners with private water systems have found that more than 80 percent are satisfied with their water supply.

Despite this general satisfaction, rural homeowners often face challenges in managing their water supply. That's because, unlike public water supplies, managing private water systems is entirely the homeowner's responsibility. Some homeowners who grew up in rural areas are accustomed to private water systems, but the increased migration of city dwellers into rural areas has meant that many homeowners are unfamiliar with the basic management of these water supplies.

Homeowners may be unaware of the proper design, construction, testing, and treatment that are often necessary to ensure safe drinking water from these supplies. As a result, many problems go unnoticed. One recent study of 700 private well owners found that fewer than 20 percent were aware of the water-quality problems that existed in their drinking water.

This manual is intended as a guide for private water system owners in Pennsylvania. From proper location and construction to recommended testing and treatment strategies, it will help you make educated decisions about your water supply. Before following any of the suggestions made in this publication, check with your local, county, and state government to make certain that any existing regulations are met.

THE HYDROLOGIC CYCLE

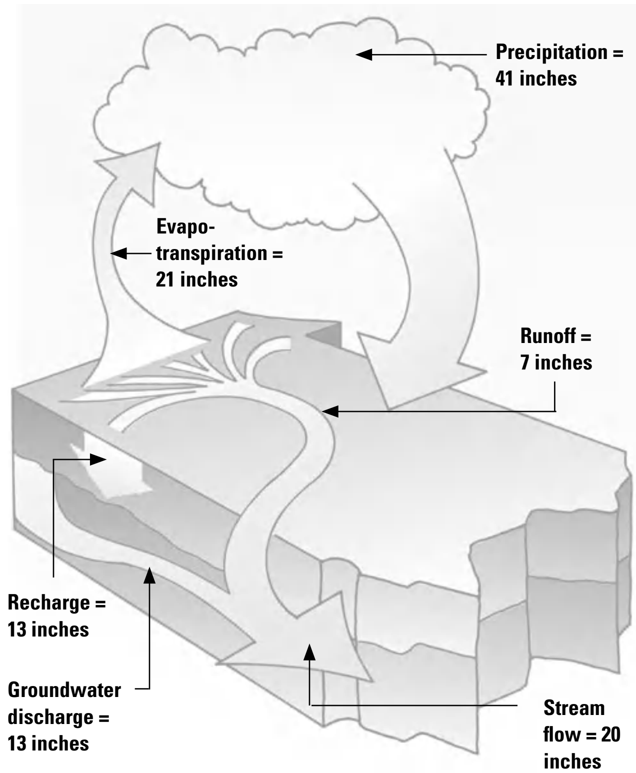
Any discussion of groundwater must start with an understanding of the hydrologic cycle, the movement of water in the environment. As the word "cycle" implies, there is no beginning or end to the hydrologic cycle; it is merely the continuous movement of water between places.

Let's start with precipitation. Rain is the dominant form of precipitation across Pennsylvania, accounting for more than 75 percent of the total annual precipitation on average. Snow is the other major form, which generally accounts for less than 10 percent of the annual precipitation in southern Pennsylvania and up to 25 percent of the annual precipitation in some northern counties. The amount of precipitation is surprisingly variable across the state, ranging from just 32 inches in Tioga County to more than 48 inches along the Allegheny Front and the Poconos. On average, the state receives approximately 40 inches of annual precipitation (rain and melted snow) as a whole.

Where does all this precipitation come from? All precipitation originates from water evaporated somewhere on the Earth's surface. Some of the rainfall in Pennsylvania comes from water that evaporated from tropical parts of the oceans. Near the equator, the sun provides enough energy throughout the year to evaporate huge quantities of water that fall as precipitation all over the world. However, precipitation during isolated thunderstorms or lake-effect snow squalls may originate from evaporation much closer to home.

The sun powers the hydrologic cycle, evaporating water from all over the Earth's surface, including water in oceans, lakes, fields, lawns, rooftops, and driveways (Figure 1.1). Plants also use the sun's energy to evaporate water by taking it from the soil, using it to grow, and releasing it into the atmosphere through their leaves in a process called transpiration. Evaporation and transpiration are commonly combined and referred to as evapotranspiration (ET). Nearly all the precipitation that falls during the growing season in Pennsylvania is returned to the atmosphere through ET. During the winter months, however, very little ET occurs because plants do not use much water and the sun is too low in the sky to cause much evaporation. Over the entire year, about 50 percent of the precipitation that falls across the Commonwealth returns to the atmosphere through ET.

Figure 1.1. The hydrologic cycle for an average year in Pennsylvania.



What happens to precipitation that reaches the earth and is not evaporated or transpired by plants? About 7 inches of Pennsylvania's annual precipitation enters streams directly as runoff, either as overland flow, which travels over the land surface, or as interflow, which moves toward streams through soil. The remainder of the precipitation, about 13 inches, is in the form of recharge—precipitation that infiltrates the soil surface, trickles downward by gravity, and becomes the groundwater that feeds the springs, streams, and wells of Pennsylvania. Most of this recharge occurs from rain and melting snow during early spring and late fall when the soil is not frozen and plants are not actively growing. Adequate precipitation and snowmelt during these short time periods is critical for supplying groundwater. All groundwater was once surface water, and it will be again because groundwater is an integral part of the hydrologic cycle. This is nature's way of recycling water.

GROUNDWATER BASICS

Precipitation that does not quickly run off into streams, is not evaporated by the sun, or does not get taken up by plant roots slowly infiltrates through layers of soil and rock to become groundwater. This infiltrating water eventually reaches a saturated layer of sand, gravel, or rock called an aquifer. Aquifers may occur a few feet below the land surface, but they are more commonly found at depths greater than 100 feet in Pennsylvania. Some groundwater occurs in the pore spaces of solid rock, but most occurs in cracks and fractures in rock layers or between sand and gravel particles. Therefore, groundwater normally occurs in small spaces within the different aquifer materials and not as underground lakes or rivers (Figure 1.2).

Geologic formations called aquitards may also lie within the saturated zone. These formations are usually made of clay or dense solid rock that inhibits infiltrating groundwater from moving through it. Aquitards restrict groundwater movement to and between aquifers. Aquitards located above and below an aquifer form a confined aquifer. If this aquifer is tapped with a well, artesian pressure forces the trapped water to rise in the well to an elevation higher than the top of the aquifer unit. If the pressure is great enough, the water may rise to the land surface, creating a flowing artesian well. An aquifer with no aquitard above it is an unconfined aquifer. In wells penetrating this type of aquifer, the water level within the well and the aquifer are the same. At any given location, several distinct aquifers may exist below the ground surface at different depths separated by aquitards.

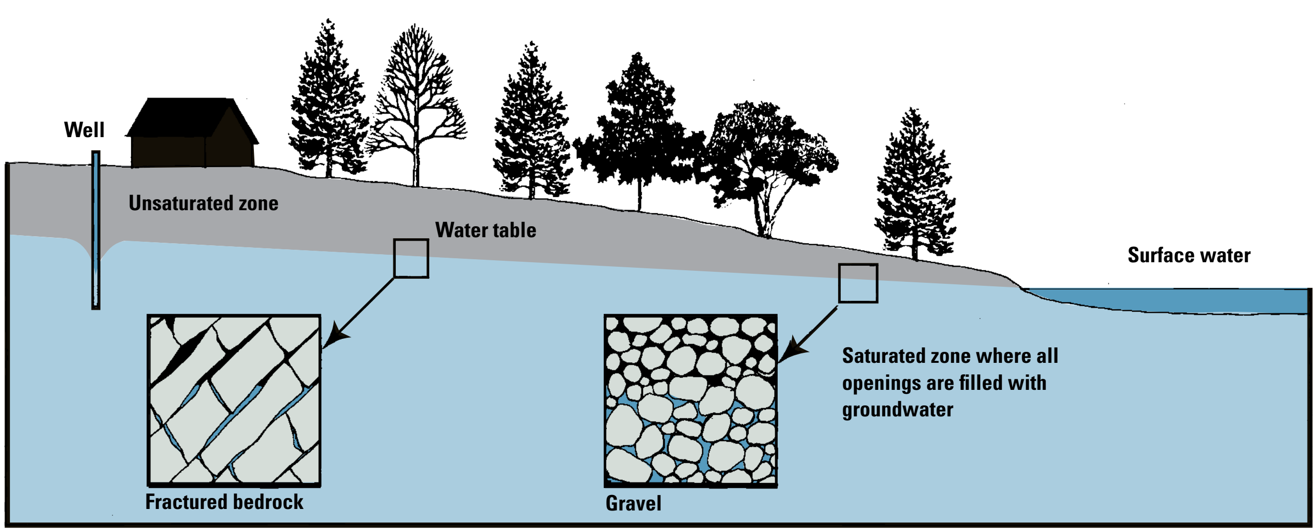
The top of the uppermost unconfined aquifer is called the water table. During rainfall, the water table rises toward the ground surface as percolating rainfall is added to the groundwater aquifer. During dry periods, the water table will fall deeper underground as groundwater is discharged from the aquifer into springs, streams, and wells.

Directly above the water table lies the unsaturated zone, where the spaces between soil and rock particles contain both air and water—air in the larger openings, water in the smaller ones. Moisture conditions in the unsaturated zone vary greatly depending on the weather. Immediately after a heavy rain, even the large pores of the unsaturated zone may hold water. During a drought, most pores are filled with air, and the little remaining water exists in thin films around soil particles.

Groundwater does not simply remain stagnant under the ground. Rather, it moves underground from upland to lowland areas. Groundwater flows downhill—the direction of groundwater flow underground can often be approximated by visualizing how water would flow on the ground surface. Flowing groundwater eventually reaches a discharge point where the water table meets the land surface. Springs are a classic discharge point where groundwater bubbling to the surface can be seen. Low-lying wetlands are another example of a discharge point where groundwater is at the soil surface.

Streams and lakes are the normal points of discharge for groundwater. Every stream has a watershed, which encompasses the land area that drains surface and groundwater into the stream. Very small streams

Figure 1.2. How groundwater occurs below the Earth's surface.



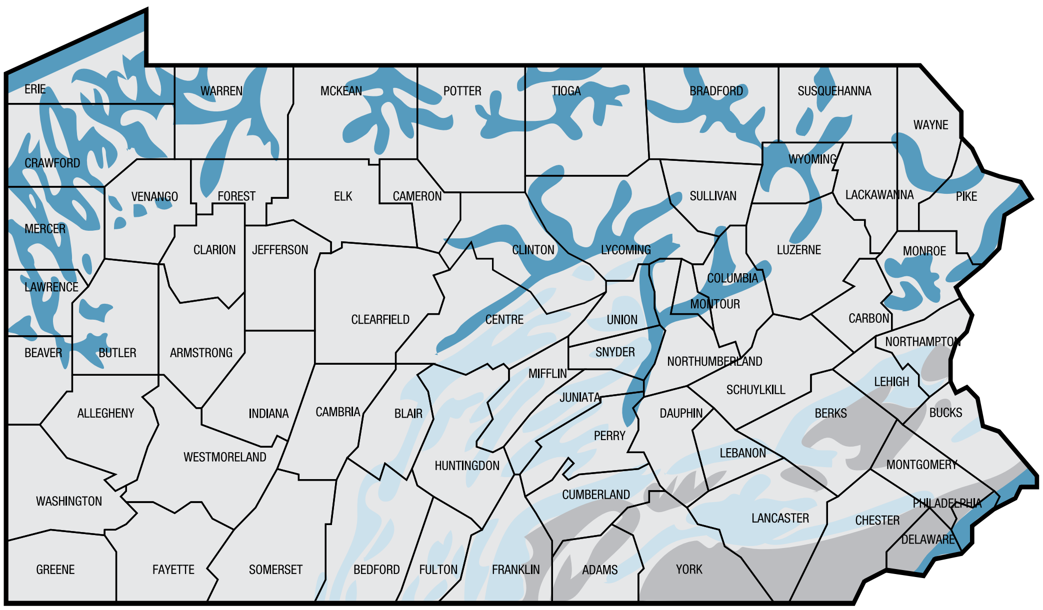
may have a watershed of only a few acres, while major rivers have watersheds that encompass millions of acres. No matter where you stand, you are located within one small watershed that is part of many other larger watersheds. The largest rivers forming the major watersheds of Pennsylvania all flow toward one of the oceans.

The average Pennsylvania stream gets about two-thirds of its flow from groundwater. Except for a short time during and after rainstorms and snowmelt, streams carry water provided only by groundwater that seeps through stream banks and streambeds into the channel (this is called baseflow). The groundwater that forms a stream's baseflow during dry weather often takes a year or more to make the journey underground to the streambed. In some groundwater flow paths, it may take thousands of years for an individual water molecule to travel to the stream after it reaches the land surface as precipitation.

The situation is sometimes reversed—streams may lose some of their flow to groundwater. This happens when the water table lies below a stream and does not intersect it. In some cases, different sections of streams behave differently, with some portions gaining groundwater and other losing it. In general, as streams become larger as they near the ocean, they contain increasing amounts of groundwater.

Groundwater aquifers vary in size and composition, and the amount and quality of groundwater yielded is also different from aquifer to aquifer. There are four major types of groundwater aquifers in Pennsylvania (Figure 1.3).

Figure 1.3. The four major types of groundwater aquifers in Pennsylvania.



Aquifer type and description		Depth (ft) Common range	Depth (ft) May exceed	Yield (gal/min) Common range	Yield (gal/min) May exceed	Typical water quality
Unconsolidated sand and gravel aquifers: sand, gravel, clay, and silt		20–200	250	100–1,000	2,300	Soft water with less than 200 mg/l dissolved solids; some high iron concentrations
Sandstone and shale aquifers: fractured sandstone and shale		80–200	400	5–60	600	Sandstone layers have soft water with less than 200 mg/l dissolved solids; shale layers have hard water and 200–250 mg/l dissolved solids
Carbonate rock aquifers: fractured limestone and dolomite		100–250	500	5–500	3,000	Very hard water with more than 250 mg/l dissolved solids
Crystalline rock aquifers: fractured schist and gneiss		75–150	—	5–25	220	Soft water containing less than 200 mg/l dissolved solids; some moderately hard water with high iron concentrations

Note: ft = feet; mg/l = milligrams per liter; gal/min = gallons per minute

From ***Pennsylvania Geological Survey***, 1999

An Important Resource

Groundwater in Pennsylvania is a vast resource and is estimated to be more than twice as abundant as the amount of water that flows annually in the state's streams. Pennsylvanians have tapped into this important resource. Each day more than one billion gallons of groundwater are pumped from aquifers throughout the state for various uses. More than half of this groundwater is used for domestic drinking-water supplies, which demand high-quality, uncontaminated water. Although smaller amounts of groundwater are used for agricultural and mining purposes, groundwater still accounts for the majority of all the water used for these activities (Figure 1.4).

Groundwater is especially vital to rural areas of the state. Second only to Michigan for the largest number of private water wells, Pennsylvania has more than one million private water wells, supplying water to more than three million rural residents (Figure 1.5). An additional 20,000 new private wells are drilled each year around the state.

Although more groundwater wells are drilled each year, the total groundwater usage across the state has remained relatively stable over the past few decades. Water conservation measures and education have played an important role in keeping groundwater use constant. From 1985 to 1995, Pennsylvania's population increased by nearly 300,000, but average water use fell from 66 to 62 gallons per person per day. Water conservation measures, such as low-flush toilets, front-loading washing machines, low-flow showerheads, and outdoor rain barrels, can reduce household water use by 30 percent. Reduced outdoor water use is especially important because it saves water that largely evaporates (consumptive water use) as opposed to water that is simply used and put back into the ground (nonconsumptive water use).

In addition to water savings, water conservation can also reduce yearly home energy costs by several hundred dollars in every home. Thus, conserving water means conserving energy. More information on water conservation can be found in Chapter 6.

THREATS TO GROUNDWATER

People from many parts of Pennsylvania are concerned about the future availability of adequate groundwater for meeting home and business needs. In some cases, these concerns are due to increasing local use of groundwater that exceeds the amount of recharge supplying the aquifer. More often, groundwater supplies are threatened by expanding impervious coverage of the land surface. Each year, more land area is being covered by roofs, sidewalks, driveways, parking lots, and other surfaces that do not allow rainwater to recharge the underlying groundwater aquifers. Every acre of land that is covered with an impervious surface generates 27,000 gallons of surface runoff instead of groundwater recharge during a one-inch rainstorm. Without recharge water feeding the aquifer, groundwater mining—water being removed from the aquifer more quickly than it can be recharged—may occur.

Groundwater mining has been documented in parts of southeastern Pennsylvania, where impervious cover has increased rapidly and groundwater withdrawals have also increased. Water-resource planning efforts initiated in Pennsylvania in 2003 aim to document areas where groundwater resources are currently overused or may be overused in the future. With this information, local government planning officials can more adequately guide future development based on existing water resources.

Figure 1.4. Groundwater use in Pennsylvania.

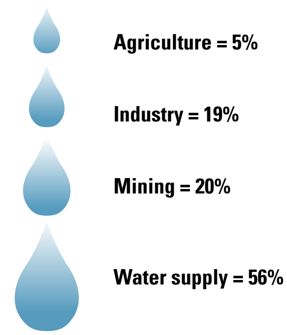
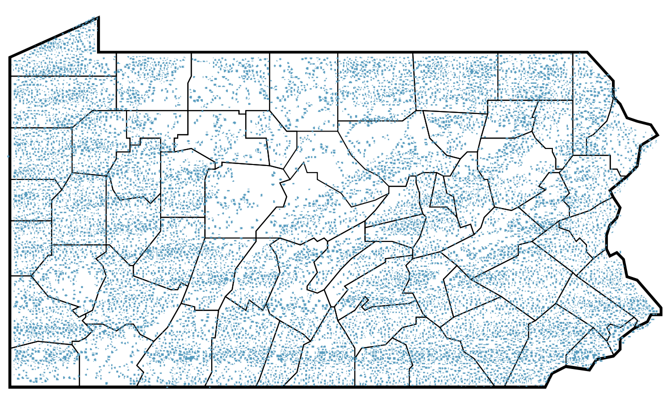


Figure 1.5. Private water wells reportedly drilled between 1963 and 1994 to serve individual homes in Pennsylvania. Each dot represents one drilled well. *Data from the Pennsylvania Groundwater Information System compiled by the Pennsylvania Geological Survey.*



Over one million homes in Pennsylvania rely on a private water system. A private water system is any well, spring, or cistern that provides the drinking water supply for an individual household. Unlike public water systems, all the maintenance, testing, and treatment of a private water system is the homeowner's responsibility. For this reason, it is important for homeowners to understand private water systems and do periodic inspections and maintenance.

A private water well is a hole in the ground that is drilled, driven, or hand dug to supply water for an individual household. Most wells today are drilled by means of a cable tool (percussion) or by the air-rotary method. Hand-dug wells are usually very old but do still exist; they need to be closely monitored since they are very susceptible to pollution from surface sources and may also contribute to aquifer contamination. All private wells should be constructed using sanitary materials, such as a water-tight, vermin-proof well cap and a cement or bentonite grout seal between the borehole and the well casing.

A spring occurs where groundwater discharges to the earth's surface. If developed properly and treated for bacteria, springs can provide a safe and reliable source of water for an individual homeowner. Considerations such as the quantity of water that the spring produces throughout the entire year should be evaluated before the spring is used as the sole source of drinking water for the home.

Cisterns are the third type of private water system found in Pennsylvania. Although uncommon in most of the state, they are used in areas where the groundwater supply is grossly polluted and there is no alternative source for drinking water. A cistern is a tank, usually installed underground, that stores water for drinking and other household uses. Cisterns can store water that is trucked to the home or they can store treated rainwater. For a household to use rain as a source of drinking water, a roof catchment area needs to be installed and the appropriate treatment systems implemented. Water from rainwater cisterns must be disinfected before it can be used as a drinking water supply.

More information about each type of private water system can be found in this chapter. Regardless of which system is used in your home, it is important that the water supply be tested at least annually by a certified laboratory to ensure that the water is safe for consumption. In Pennsylvania, private water supplies are not monitored or regulated by the state, so homeowners need to evaluate their own systems periodically.

WATER SYSTEM PLANNING: ESTIMATING WATER NEEDS

Whether you are building a new house in a rural area or increasing the size of a dairy herd, an adequate supply of water from a private well or spring is critical to your plans. Planning should be done before you have a well drilled or spring developed to ensure that enough water is available.

This section allows a homeowner or farmer to estimate water needs and calculate how much water must be delivered from a private water supply to meet these needs. These planning assumptions are based on long-term averages for various water uses in Pennsylvania. Your actual water use may vary significantly from these averages.

Estimating Home Water-Use Needs

In general, we use 50 to 100 gallons per person per day in our homes (200 to 400 gallons per day for a family of four). The household water use estimates given in Table 2.1 can be used to calculate more specific daily water use values for your home.

For the purposes of planning a water system, the total daily water use is less important than the peak daily water use or the *peak demand*. In reality, most of

Table 2.1. Typical water uses for various appliances and fixtures in the home.

Clothes washer (top-loading)	43 to 51 gallons per load
Clothes washer (front-loading)	27 gallons per load
Dishwasher (standard)	7 to 14 gallons per load
Dishwasher (efficient)	4.5 gallons per load
Garbage disposal	4 gallons per day
Kitchen sink	3 gallons per minute of use
Bathroom sink	2 gallons per minute of use
Shower or tub	5 gallons per minute of use
Toilet (low-flush)	1.6 gallons per flush
Toilet (standard)	5 gallons per flush
Outside hose (1/2-inch)	5 gallons per minute of use
Water softener regeneration	50 to 100 gallons per cycle

the water used in the home occurs over very short time periods, usually in the morning and evening. As a result, for planning purposes it is recommended that a water system be able to supply all of the day's projected water use in a 2-hour peak demand period. If you estimate that your home water use will be 400 gallons per day, the water system should be sized to provide this much water in a 2-hour period.

The amount of water that can be delivered from your well or spring in a given period of time is referred to as the well or spring yield. The yield from a spring can be easily measured by determining how many gallons of water flow from the outlet pipe every minute. This flow rate will likely vary considerably with weather conditions, but, for planning purposes, it would be best to measure flow during a dry time period. For a well, the yield is considered the maximum rate in gallons per minute (gpm) that a well can be pumped without lowering the water level in the borehole below the pump intake.

For most single-family homes, a minimum flow of 6 gpm is suggested from a well or spring. This flow would provide 360 gallons of water each hour, which would be sufficient to meet most home water peak demands. Higher flow rates may be necessary for larger homes with more fixtures, appliances, and residents that may all be using water at the same time. The values in the table below give the suggested minimum flow rates for various numbers of bedrooms and bathrooms in a home.

Ideally, the yield from the well or spring will exceed the recommended minimum flow rates in Table 2.2. If not, you may need to rely on water storage to meet peak demand periods. For a drilled well, the borehole can provide a significant amount of water storage. A typical 6-inch-diameter well stores about 1.5 gallons of water for every foot of standing water in the borehole, and a 10-inch well stores about 4 gallons of water per foot. Therefore, a 6-inch-diameter well with about 100 feet of standing water in the borehole would contain about 150 gallons of stored water. However, in some geologic settings, using a significant amount of the borehole storage (i.e., significant drawdown for each pumping cycle) may tend to dislodge particles from the borehole and may result in the need to filter the water.

In the case of a spring, a large spring box can be constructed where the spring emerges, or a water storage tank can be added after the spring box to provide extra water storage to meet peak demand. The water stored in the borehole, spring box, or storage tank is helpful when water use in the home exceeds the amount of water flowing from the well or spring.

Well storage and spring flow can vary dramatically with the natural groundwater level, with the highest levels typically occurring in spring and the lowest levels in fall. These natural variations can be accentuated by drought conditions. So, while water storage can allow for the use of wells and springs with lower flow rates than shown in Table 2.2, it may not be reliable during severe droughts. An approximate estimate of the amount of water needed before a well or spring is developed can allow the professional contractor to use the combination of local knowledge, yield, and storage to meet water demand. For wells that yield extremely low amounts of water, an intermediate storage system can be added (see "Low-Yielding Wells" in Chapter 6).

Estimating Farm Water-Use Needs

Planning for water supply needs is generally much more important for farms because much larger amounts of water are often needed, especially for dairy operations or farms with large acreages in irrigation. Midwest Plan Service guidelines suggest that farms using 2,000 gallons per day (gpd) will need a water source flow rate of 16 gpm, those using 6,000 gpd will need 36 gpm, and those using 10,000 gpd will need 48 gpm. Planning for larger operations starts with an estimate of total daily water use from Table 2.3.

Using the estimates from Table 2.3, current and future daily water demands on the farm can be estimated. The farm water system would need to be designed to include sustained yield and storage from one or more wells or springs. Where large quantities of water are needed from a well, it may be worthwhile to hire a professional hydrogeologist to locate a high-yield well using fracture trace mapping or other technique for locating a productive well.

It should also be noted that farms using more than 10,000 gpd must report their annual water use to the Pennsylvania Department of Environmental Protection as required by the Water Resources Planning Act.

Table 2.2. Minimum flow rates (GPM) for homes based on number of bedrooms and bathrooms.

Number of bedrooms in home	Number of bathrooms in home			
	1	1.5	2	3
2	6 GPM	8 GPM	10 GPM	
3	8 GPM	10 GPM	12 GPM	
4	10 GPM	12 GPM	14 GPM	16 GPM
5		13 GPM	15 GPM	17 GPM
6			16 GPM	18 GPM

From *Private Water Systems Handbook.* 1002. Midwest Plan Service. MWPS-14.

Table 2.3. Estimated daily water use in gallons for various farm animals, equipment, processes, and irrigation in Pennsylvania.

Animal water use	
Milking cows	35 gallons per animal per day
Sprinkler cooling for animals	20
Dry cow, beef cattle, or steers	12
Calves	
1-month-old	1.5
2-month-old 2.0	2.0
3-month-old	2.5
4-month-old 3.5	3.5
5 to 14 months old	4.5
Heifers	
15 to 18 months old	7.0
18 to 24 months old	
Swine	1.5
Horses or ponies	12
Sheep or goats	2
Chickens (per 100)	9
Turkeys (per 100)	15
Milkhouse and parlor water use	
Automatic bulk tank	50 to 60 gallons per wash
Manual bulk tank	30 to 40 gallons per wash
Pipelines	70 to 120 gallons per wash
Pail milkers	30 to 40 gallons per wash
Milking system clean-in-place (parlor)	12 to 20 gallons per unit
Miscellaneous equipment	30 gallons per day
Cow preparation (per milking)	
Automatic	1 to 4.5 gallons per cow
Manual	0.25 to 0.5 gallons per cow
Wash pen	3 to 5 gallons per cow
Milkhouse floor	10 to 20 gallons per day
Parlor floor (hose down)	50 to 100 gallons per wash
Parlor floor and cow platform	500 to 1,000 gallons per wash
Parlor and holding area floor with flushing	
Parlor only	20 to 30 gallons per cow
Parlor and holding area	25 to 40 gallons per cow
Holding area only	10 to 20 gallons per cow
Automatic flushing	1,000 to 2,000 gallons per wash
Irrigation	
Sprinkler*	4,000 gallons per acre per day
Drip*	1,000 gallons per acre per day

*The amount of water used for irrigation is seasonal and varies greatly depending on natural water availability from precipitation.

The required water source flow rate does not necessarily need to equal the yield from the well or spring. If water availability is projected to be insufficient for the calculated peak water demand, additional sources must be developed or additional storage must be used (see "Low-Yielding Wells" in Chapter 6).

PROPER CONSTRUCTION AND MANAGEMENT OF PRIVATE WATER WELLS

Before You Drill a Well

When the decision is finally made to try using groundwater as a water supply for domestic use, livestock, and farmstead demands or irrigation, it is important that certain procedures be followed to ensure a clean, reliable, productive well. These important steps include siting, drilling, and pump testing the well. Although following the recommendations in this publication will not guarantee all the clean water you may need or desire to have, it will greatly increase your chances of having a clean, reliable, productive well that is able to meet your needs.

Finding a Qualified Driller

In most states, regulations were created to ensure that private water wells are constructed properly. In a few states, however, no private water well regulations exist. In this case, a well can be drilled using any materials, and the driller does not have to follow designated guidelines. In states without regulations, it is possible for well drillers to lack qualifications or training. Therefore, it is very important that you take the time to find a qualified well driller to make certain that the system is constructed properly. Find out if the driller is associated with any organizations such as a state association of well drillers or the National Ground Water Association. Usually well drillers with memberships in these organizations are more educated about proper well construction.

Also, talk to each well driller about the construction of your well. Tell the well drillers that you are interested in the process and see if they will take the time to explain what they are going to do. Find a qualified well driller at www.wellowner.org.

Before work starts, make sure to get a written contract that gives you a breakdown in cost and materials, provides liability insurance for the driller, and provides a guarantee of workmanship, etc.

The Proper Location

Groundwater exploration is not a hit or miss (or random) proposition. Excess rainwater percolates into the soil and rock beneath the earth's surface, accumulating in zones of saturation called aquifers. A well is a hole drilled into the aquifer from which a small portion of the groundwater can be pumped to the surface for use. It is true that any well penetrating an aquifer will yield water, but the amount of water produced from a randomly sited well may be very small.

Scientific methods have been developed for locating wells; such methods involve penetrating zones of fractured rock buried beneath the soil surface. Wells located on a fractured rock zone will produce much larger quantities of water than wells drilled into zones where the rock is not fractured. Finding the fractured rock zones, or better yet, finding the intersection of two fractured rock zones can be a time-consuming and expensive procedure. Only licensed geologists with training in aerial photo interpretation and hydrogeology are qualified to locate wells by the fracture-trace technique. If a high-producing well is desired, however, the consultant's fee for siting the well is money well spent.

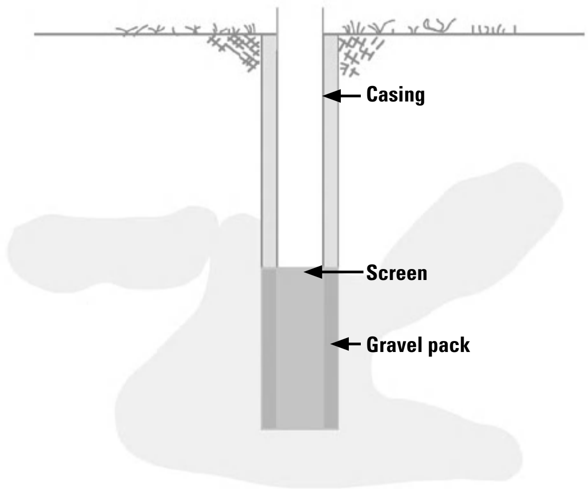
In addition to the siting considerations discussed above, which pertain to finding adequate water, wells should be located at least 50 feet from sewers and septic tanks; at least 100 feet from pastures, on-lot sewage system absorption fields, cesspools, and barnyards; and at least 25 feet from a silo. These distances are for residential wells and should be increased for farm wells in proportion to the demand placed on the well. Areas where groundwater comes to within 10 feet of the soil surface should also be avoided.

Drilling the Well

Drilling a well is more than boring a hole into the earth. A finished well consists of a borehole drilled into the aquifer at a diameter large enough to accept the well casing (see Figure 2.1), which receives the pump. The decision about how large the pump must be to meet your intended demand must, therefore, be made before drilling starts. The well casing is sized to meet the expected pumping need. For instance, a 6-inch casing will receive pumps that can pump up to approximately 100 gallons per minute (gpm). If you desire to pump more than 100 gpm you will need an 8-inch casing, which dictates at least a 12-inch borehole. Your well driller will actually make these decisions, but he must know your needs.

The borehole itself can be drilled using any one of several types of drill rigs, including impact, rotary, or various combinations. After the borehole has been drilled into or through the water-bearing aquifer, the well screen may be installed in the producing zone of the unconsolidated aquifer, or the well may be com-

Figure 2.1. Well components.



pleted as an open borehole if it is drilled into a rock formation. The zones above the producing aquifer must be cased to prevent cave-ins, and the annulus (space) between the borehole and casing must be filled with grout to keep surface contaminants from entering the well. Read more about grouting later in this chapter.

Developing the Well

Developing a well is the process of clearing the well of fine particles ("fines") left by the drilling operation, and flushing these fines out of the borehole and the first few feet of the aquifer. Development is accomplished by washing, air surging, bailing, or any operation that forces water through the development zone at high velocities. Developing a well is best done by the well driller right after the well is drilled. Properly developed wells may yield more water and will probably produce less turbidity (sediment) than poorly developed wells.

Pumping Test

With the well in place, the question remains, "How much water can be pumped from the well on a sustained basis?" The sustained pumping rate is dependent on the aquifer's ability to move water toward the well under the influence of gravity while the well is being pumped. To determine the sustained pumping capacity of a well, a "pumping test" should be performed on the well. The pumping test may be completed by the contractor as part of the well drilling contract. The desire for a pumping test must be made clear to the driller before drilling begins because some drillers are not able to do the pumping test.

Be sure to use a driller who can complete all drilling work, including the pump test.

Several types of pumping tests have been developed, but all are designed to establish the long-term equilibrium rate at which water will flow towards and enter the well. The simplest, most straightforward pumping test is to place a pump in the well, after the development phase is complete, and to pump water from the well at a constant rate. The pumped water must be discharged some distance from the well so it cannot recirculate back into the well during the pump test.

The pumping rate should be great enough to stress the well, but not so great as to cause the well to be pumped dry. During the pumping test, the water level in the well must be measured and recorded at regular intervals, starting at the time pumping begins and continuing until pumping stops. Pumping test durations for residential purposes are on the order of several hours; higher-yielding municipal and agricultural wells may have pumping tests that last for 24 to 72 hours or longer.

A cone of depression is produced when water is removed from the well bore by the pump, causing the water level in the well to drop. This means the water surrounding the well is at a higher elevation and the water in the rock begins to flow into the well bore. As this continues, the distance between the original water table and the water level in the well, or drawdown, increases and forms a cone of depression. At some point, the drawdown reaches a point of equilibrium, where the water flows to the well at the same rate as it is being pumped from the well, and the change in drawdown over time becomes very small or negligible.

The capacity of a well can be estimated by first determining the well's "specific capacity." Specific capacity (Sc) of a well is the pumping rate (Q) in gallons per minute (gpm) during the pumping test, divided by the drawdown (s) (in feet) at equilibrium. In other words, the specific capacity is the flow rate per foot of drawdown.

$$Sc = Q\ (\text{gpm}) \ / \ s\ (\text{ft})$$

Knowing the depth of the well and where the permanent pump will be placed, you can assume the maximum permissible depth to water in the well to be 10 feet above the permanent pump intake location. The difference in elevation between the original water table and the maximum permissible depth to water is the maximum drawdown, Smax. The maximum sustainable discharge for the well is then the specific capacity times the maximum drawdown.

$$Qmax = Sc\ (Smax)$$

Keep in mind that this method for estimating maximum sustainable discharge may overpredict sustainable discharge if the well is used continuously or for more than residential or light agricultural use. After the pumping test is completed, you will have gained knowledge about how much water the well can be expected to produce.

Sanitary Well Caps and Grouting

Pennsylvania is one of only a few states that do not have mandatory statewide construction standards for private water wells. (A few counties and townships have passed well construction ordinances—check with your local government office to determine if they are required in your area.) As a result, some important components of a properly constructed drinking water well are often not installed in an effort to reduce the cost of the well to the homeowner. The most important features missing from most private wells are a sanitary well cap and a grout seal. These components are required by most states because they help protect groundwater by sealing the well from potential surface contamination.

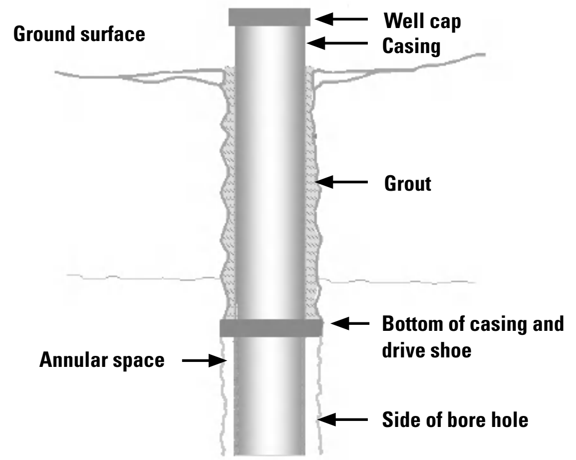
Types of Well Caps

Most existing and new wells in Pennsylvania have a standard well cap similar to the one shown in Figure 2.2. Standard well caps usually have bolts around the side that loosely hold the cap onto the top of the casing. Since these caps are nonsealing, the small airspace between the well cap and the casing can allow for insects, small mammals, or surface water to enter the well.

Figure 2.2. A standard well cap similar to those found on most Pennsylvania wells.

Figure 2.3. A sanitary well cap installed on a well casing.

Figure 2.4. Cross-section of a well casing showing the grout used to seal the annual space around the casing.



A "sanitary" well cap (sometimes referred to as a "vermin-proof" well cap) looks similar to a standard well cap but usually has bolts on the top of the well cap as shown in Figure 2.3. Most sanitary well caps include an airtight rubber gasket seal to prevent insects, small mammals, or surface water from entering the well and a small, screened vent to allow for air exchange.

What Is a Grout Seal?

Grout is usually neat cement (no aggregate) that is pumped into the space between the drilled hole and the casing—called the *annular space* (Figure 2.4). Bentonite, a clay material that expands when wet, is also often used for grouting a well. The grout is pumped into the annular space starting from the bottom of the casing using a tremie pipe. The grout is added until it appears at the surface of the ground. Since there are no residential well construction standards in Pennsylvania, grouting might not necessarily occur during the construction of a private well unless it is required by local ordinances, requested by the homeowner, or a part of the well contractor's standard operating procedure.

Can an Existing Well Be Grouted?

In general, it is not possible to grout an existing well. In rare cases, it may be possible to install a smaller diameter casing inside the old casing and grout between the casings. Another method used on existing wells is to pour a concrete slab around the existing well casing. However, these concrete slabs often crack and provide minimal protection from surface contamination. The best protection for an existing well is to make sure that the ground surface slopes away from the well casing in all directions to direct surface water away from the wellhead area.

Bacterial Contamination

Sanitary well caps and grout seal are installed primarily to prevent surface contamination, especially bacterial contamination. Bacterial contamination is a common problem that occurs in about 40 percent of the private water wells in Pennsylvania. Drinking water is typically tested for *total coliform bacteria*, which includes a large number of different species of bacteria, some of which can cause illnesses or diseases. For this reason, all drinking water supplies should be free of coliform bacteria. More information about coliform bacteria can be found in Chapter 4.

Bacterial contamination of groundwater wells can occur from both above and below the surface. Pollution of entire groundwater aquifers affecting many wells may occur from failing septic systems or animal wastes. Similarly, individual wells may be contaminated from the surface if contamination sources are located near the wellhead. Surface contamination of individual wells is usually caused by surface water or shallow soil water flowing down the outside of a well casing through the annular space; it can also be caused by a loose-fitting or absent well cap that allows insects, animals, or surface water to directly enter the well. Sanitary well caps and a grout seal can help prevent this type of contamination from occurring.

Does a Grout Seal and Sanitary Cap Prevent Contamination?

A 2002 study by the U.S. Geological Survey of more than 100 private wells in Pennsylvania examined the importance of grout in preventing bacterial contamination. This study found that ungrouted wells were three times more likely to be contaminated with *E. coli* bacteria compared to grouted wells. This same study, however, found that coliform bacteria were still quite common in grouted wells. Since the wells used in this study did not have sanitary well caps, the authors theorized that coliform bacteria were entering the well from the well cap area. This was supported by their visual assessment that found nearly 50 percent had obvious insect infestations under the well cap. Insects were found inside the well cap, on the wiring or plumbing, or inside the casing. Another study by the Wisconsin Department of Natural Resources found that insects could be a source of coliform bacteria in wells.

A recent Penn State study documented the effect of installing a sanitary well cap on existing water wells. Sixteen private wells containing coliform bacteria were disinfected with chlorine and fitted with a sanitary well cap. Of these wells, 44 percent did not contain coliform bacteria one month later and 19 percent did not contain bacteria after one year. The sanitary well caps were most successful in eliminating bacteria from wells that previously contained small numbers of coliform bacteria (less than 3 colonies per 100 mL of water), compared to those that had more gross contamination.

The study also looked at bacterial contamination in new wells that had been constructed with a sanitary well cap and a grout seal. Only 29 percent of these new wells contained coliform bacteria, suggesting that proper well construction practices can reduce but not completely eliminate bacterial contamination. Wells drilled into aquifers contaminated by animal wastes, septic systems, or surface water can contain coliform bacteria regardless of well construction practices.

What About the Cost?

Sanitary well caps and a grout seal are generally not used on private wells because of the added cost unless they are required by local ordinance. Sanitary well caps typically cost $40 to $50 compared to $20 to $30 for a standard well cap. A sanitary well cap can be installed by a homeowner with some basic knowledge of electrical wiring, or the cap can be installed by a well driller. In the recent Penn State study, the average cost for disinfection and installation of a sanitary well cap by a well driller was about $100 per well. Grouting of a new well typically adds $500 to $1,000 to the cost of the well. The cost of grouting will depend on the well depth, diameter, and type of bedrock in the area. It is the prerogative of educated consumers to therefore determine how best to spend their investment dollars—on proper well construction employing best practice methodology or on treatment equipment to address water-quality issues that may be related to substandard well construction.

What Can You Do?

Contamination related to an inadequate well cap or missing grout seal will most likely result in the presence of coliform bacteria in your well water. The first step in properly managing an existing private well, therefore, is to have an annual test done for total coliform bacteria. You can arrange this test through a local certified laboratory (a list of labs is available online at water.cas.psu.edu) or, in Pennsylvania, your regional Department of Environmental Protection office.

If your well tests positive for coliform bacteria, a sanitary well cap may help solve the problem, especially if your well contains small numbers of bacteria. Even if your well is currently free of bacteria, a sanitary well cap will help ensure that it does not become contaminated in the future by insects or other contaminants around the wellhead. Sanitary well caps can usually be purchased from a local water well contractor. Consult www.wellowner.org to find a local water well contractor certified by the National Ground Water Association. The contractor can also be hired to disinfect the well and install the sanitary well cap if you desire.

If you do the work yourself, the existing well cap should be removed and any obvious insects, nests, or small mammals should be removed from inside the well casing. Existing bacteria in the well water can be killed using a chlorine solution before installing the new well cap. (Note: installing the well cap should be done with caution owing to the involvement of electrical wiring.) Information about shock chlorinating your well can be found in Chapter 5. If you are having a new well drilled, you should request that the well be grouted to prevent surface contamination. If you have an existing grouted or ungrouted well, make sure the ground surface is sloped away from the casing in all directions to direct surface water away from the well.

Well Maintenance

After your well is properly constructed, it is very important to do preventative maintenance on an annual basis. Each year, a well owner should take the time to inspect the wellhead and the area surrounding it. This inspection should focus on finding cracks or damage to the well casing, checking the well cap to make sure it is in good condition and securely fastened, checking to make sure that water cannot pond around the wellhead, and looking for any nearby activities that could cause contamination to the water supply. You should also test your water each year at least for coliform bacteria. Include the annual water test report and notes from your annual inspection in a file that you keep with other important documents about your home.

Besides the annual preventative maintenance that a homeowner can perform, it is also beneficial to have a well inspection done by a qualified water well driller at least every ten years. Have these inspections more often if you harbor concerns about your well or the quality of your drinking water. A qualified well driller can be found at www.wellowner.org.

Dealing with Unused Wells

Pennsylvania has one of the largest rural populations of any state in the country, and most rural populations depend on private water systems for drinking water. Thus it is not uncommon to find old, unused wells throughout the state. Homeowners may choose to abandon a well on their property if it is plagued with problems and they believe that a new well will provide a high-quality water supply. A well may also go unused if it does not provide an adequate yield and a new well is thought to provide a more abundant water supply.

Regardless of the reason that a well is no longer in use, it is very important for any unused well to be properly sealed (or decommissioned) by a qualified well driller. The goal of sealing a well properly is to restore the area to the same condition (or better) that existed before the original well was drilled. An unused well that is not properly sealed becomes a direct conduit for surface contamination to affect the surrounding groundwater supply. In certain situations an unused well that is not sealed properly can lead to mixing between aquifers of poor and good water quality. Besides the potential pollution that an unused well might cause, it can also be a physical hazard and sealing it properly will help to prevent injury. *It is never acceptable for unused wells to be used for the disposal of any type of liquid or solid waste.*

Well-decommissioning Procedures

Many states have regulations detailing the procedures that should be used to properly seal an unused well. Pennsylvania currently has no statewide residential regulations regarding this process. The procedures outlined below are based on the recommendations of the National Ground Water Association. (Note: Pennsylvania has regulations and guidelines for properly decommissioning all public water supplies; guidelines for private water supplies can be found in the *Groundwater Monitoring Guidance Manual,* available from your local office of the Pennsylvania Department of Environmental Protection or on its Web site at www.dep.state.pa.us.)

The goal of sealing an abandoned well properly may vary depending on the well's construction, geological formations encountered, subsurface water chemistry, and prevailing hydrologic conditions. The basic concept governing proper sealing of abandoned wells is the restoration, as far as feasible, of the hydrogeologic conditions that existed before the borehole was drilled and the well constructed. This serves the purposes of removing the abandoned well as a conduit for loss of hydrologic pressure in confined formations, intermingling of groundwaters of differing quality, and entry of contaminated and polluted water.

The purpose of sealing an abandoned water well properly is to accomplish several objectives: (1) elimination of a physical hazard; (2) prevention of groundwater contamination; (3) conservation of yield and maintenance of hydrostatic head of aquifers; and (4) prevention of the intermingling of desirable and undesirable waters.

To seal an unusable or abandoned well or borehole properly, the hydrologic character of the groundwater encountered by the well must be considered. If the well was drilled into an unconfined aquifer (also referred to as a water table aquifer), the primary concern is to prevent surface water from entering the hole and contaminating the groundwater supply. If the unused well was drilled into a confined aquifer with artesian conditions, then the sealing procedure must be done so that water is restricted to its original aquifer and there is no loss of artesian head pressure. This will ensure that there is no contamination of surrounding aquifers or loss of artesian head pressure.

The first step in properly decommissioning a private water well is to hire a qualified professional. Use special consideration if the well to be plugged is a flowing artesian well. In this situation, you should select a driller who has extensive experience in sealing an artesian well. You can locate a well driller in your area at the Web site, www.wellowner.org. After a qualified driller is obtained, the following steps should be taken:

1. Research must be done on the well. Any records on the well, including the well log or maintenance records, should be found and given to the contractor. If no records can be obtained, then a down-hole camera and other techniques can be used to enable the contractor to gather information about the borehole.
2. It is strongly suggested that any material potentially hindering the proper sealing of a decommissioned well should be removed. In most situations, the well casing or liner should be removed from the borehole along with the pitless adapter, pump, screen, and any debris that has fallen into well. If the contractor finds that the casing cannot be removed, then it should be perforated or destroyed to the point that the pressurized grout fully comes into contact with the borehole walls

and properly seals the hole. If confirmed and documented evidence can be obtained that the annular space between the casing and borehole was indeed sealed and properly grouted during the well's installation and that these procedures were carried out in accordance with applicable state regulations and/or industry standards in absence of governing regulations, this segment of the operation can be bypassed with the agreement of all interested parties.

3. The well should be shock chlorinated (100 to 500 mg/L) to reduce the presence of bacteria and the chance that the sealed well might be a future source of bacteria for other wells in the area. In the event that chlorine concentrations greater than 100 mg/L are to be used, the contractor should consider the sealing material and methods to be used and the possible impact of elevated chlorine levels on the long-term sealing capacity of the sealing medium and method selected.
4. A grout or cement material chosen by the contractor should be used to seal the hole. The material will not plug the hole properly if it is dumped from the surface, since grout particles will separate as they fall through water. The sealing material must be introduced at the bottom of the borehole and filled up to the surface using a tremie or grout pipe, cement bucket, or dump bailer under pressure. Any borehole or well that is to be permanently sealed should be completely filled in such a manner that vertical movement of water within the well bore, including along the annular space surrounding the well casing, is effectively and permanently prevented. Methods and equipment used for the sealing should be selected based on recommendations from a qualified professional.
5. Information about the decommissioned well should be recorded and a copy of the report given to both the homeowner and the state or local regulatory agency.

More information about the National Ground Water Association and its specific recommendations for well decommissioning can be found at www.wellowner.org.

SPRING DEVELOPMENT AND PROTECTION

Springs occur wherever groundwater flows out from the earth's surface. Springs typically occur along hillsides, low-lying areas, or at the base of slopes. A spring is formed when the water table intersects the ground surface due to geologic or topographic factors. This can occur at a distinct point or over a large seepage area. Springs are sometimes used as water supplies and can be a reliable and relatively inexpensive source of drinking water if they are developed and maintained properly.

What to Consider

When considering using a spring as your source of drinking water, it is important to ensure that the rate of flow is reliable during all seasons of the year. Spring flow that fluctuates greatly throughout the year is an indication that the source is unreliable or may have the potential for contamination. It may be possible to learn about historical spring flow from the previous owner or a neighbor. Water quality is also important to consider before using a spring as a water supply. Before developing the spring, collect a sample of water and have it analyzed at a local water-testing laboratory to ensure that it can be efficiently and economically treated to make it safe for human consumption (see Chapter 4 for more information about water-testing options).

Springs may be susceptible to contamination since they are often fed by shallow groundwater, which may flow through the ground for only a short period of time and may interact with surface water. For this reason, most springs will need some treatment before the water is considered safe for drinking. Testing helps to determine exactly how much treatment is necessary and may help determine if other sources of water would be more economical.

Preparation

Since springs are often fed by shallow groundwater, water quantity may be an issue during certain times of the year. If possible, the flow rate for your spring should be monitored for an entire year, but it is most critical to measure the flow rate during late summer and fall when groundwater levels and spring flows are usually at their lowest. Springs used for drinking water supplies should yield at least two gallons per minute throughout the entire year unless water storage is going to be used. The amount of water you will need from your spring depends entirely on your household's daily water needs. Water needs for an individual home vary depending on water use, water storage, and water-saving devices within the home. However, the average home requires approximately 50 to 75 gallons of water a day per person. More information on determining your household water needs can be found at the beginning of this chapter.

The flow rate of a small spring can be tested by digging a five-gallon bucket into the outlet channel of the spring and allowing the water to flow into the bucket. Determine the flow rate in gallons per minute (gpm) by timing how long it takes the water to fill the bucket. Example below:

Flow rate = volume/time

$$= \frac{5 \text{ gallons}}{34 \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 8.9 \text{ gpm}$$

Obtain a sample collection container from a certified water lab and send a sample of the spring water to the lab for water-quality testing. A list of labs is available at water.cas.psu.edu/ or from your county Penn State Cooperative Extension office. You can start developing your spring once you determine that the quantity and quality are acceptable.

Procedures for Developing the Spring

A spring can be developed into a drinking water supply by collecting the discharged water using tile or pipe and running the water into some type of sanitary storage tank. Protecting the spring from surface contamination is essential during all phases of spring development. Springs can be developed in two different ways; the method you choose will depend on whether it is a concentrated spring or a seepage spring. The general procedures for spring development are outlined in the following pages. Some of these procedures are adapted from the Midwest Planning Service publication, *Private Water Systems Handbook*. This publication (MWPS-14) is available for purchase at www.nraes.org or by calling NRAES at 607-255-7654.

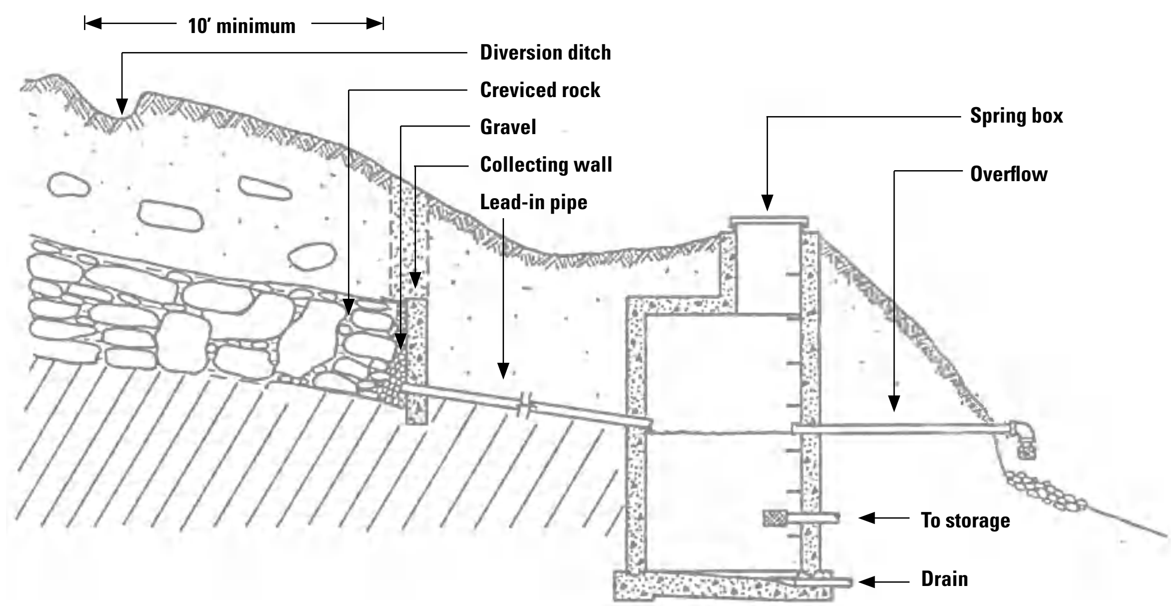
Concentrated Springs

A concentrated spring typically occurs when groundwater emerges from one defined discharge in the earth's surface. Concentrated springs are visible and are often found along hillsides where groundwater is forced through openings in fractured bedrock. This type of spring is relatively easy to develop (see Figure 2.5) and is usually less contaminated than other types of springs.

Steps for developing a concentrated spring are as follows:

- Excavate the land upslope from the spring discharge until water is flowing three feet below the ground surface.
- Install a rock bed to form an interception reservoir.
- Build a collecting wall of concrete or plastic downslope from the spring discharge.
- Install a pipe low in the collecting wall to direct the water from the interception reservoir to a concrete or plastic spring box. (Note: problems with spring flow can occur if water is permitted to back up behind the wall.)
- Remove potential sources of contamination, and divert surface water away from the spring box or collection area.
- Alternative types of interception reservoirs and collecting walls can be constructed.

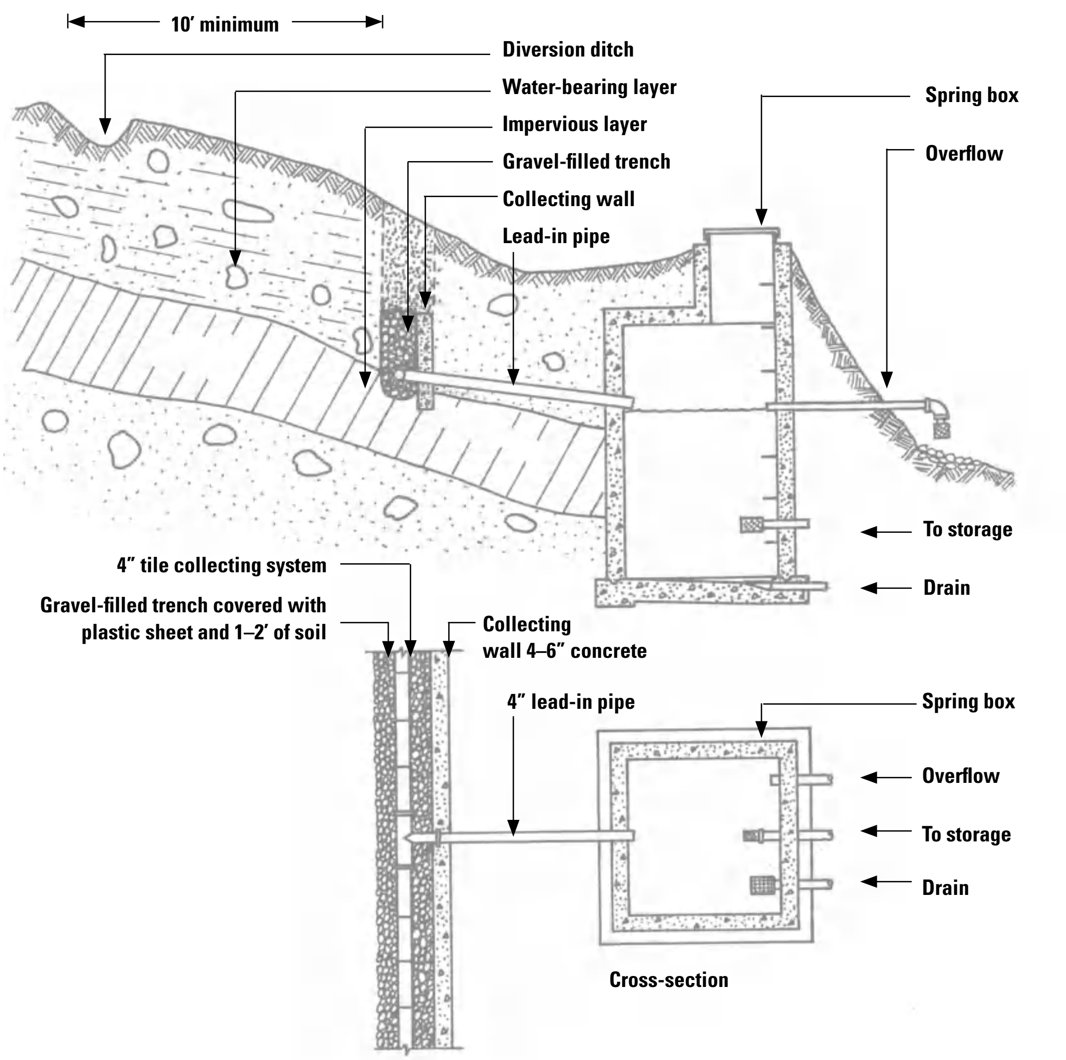
Figure 2.5. Development of a typical concentrated spring.



Seepage Springs

Seepage springs occur when shallow groundwater oozes or "seeps" from the ground over a large area and has no defined discharge point. This type of spring usually occurs when a layer of impervious soil redirects groundwater to the surface. Seepage springs can be difficult to develop (see Figure 2.6). They are also highly susceptible to contamination from surface sources, and they need to be monitored before development to ensure that they will provide a dependable source of water during the entire year. Flow is often lower from seepage springs, making them less dependable.

Figure 2.6. Spring development in a seep area.



Note: Trench should be 18–24″ (inches) wide, extend 6″ (inches) into (but not through) the impervious layer, and reach 4–6′ (feet) beyond the seep area on each side.

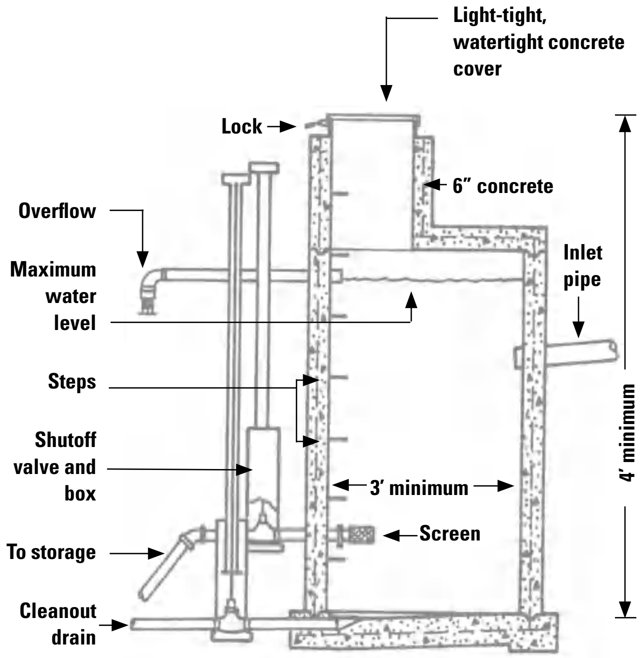
Spring Box Considerations

A spring box is a water-tight structure built around your spring to isolate it from contaminated surface runoff. (See Figure 2.7.) It is critical that this box be built properly to ensure that surface water, insects, or small animals cannot enter the structure. If designed properly, it can provide a small amount of reserve storage during a situation when the spring flow rate is below normal. It is important to keep surface water away from the spring box, and animals should be fenced out of the spring's drainage area. All activities should be kept to at least 100 feet from the spring box.

- Dig test holes upslope from the seep until you locate the point where the impervious layer is 3 feet underground.
- Create a trench approximately 18 to 24 inches wide across the slope. The trench should be extended 6 inches into the impervious layer (below the water-bearing layer) and should extend 4 to 6 feet beyond the seepage area. Install 4 inches of perforated pipe and surround it with gravel.
- Installing a collecting wall will help prevent water from escaping the collection tile. This collecting wall should be constructed of 4 to 6 inches of concrete.
- Perforated pipe or collection tile should be connected to 4-inch pipe that leads to the spring box. The box inlet must be below the elevation of the collector tile.
- Remove potential sources of contamination and divert surface water away from the spring box and collection area (Figure 2.8).

Figure 2.7. Spring box example.

Figure 2.8. Spring box construction.



Proper Management of Springs

No matter what type of spring you have developed, it is critical that you remove potential sources of contamination from the spring's drainage area (the area upslope of the spring discharge point). Make sure to keep water-quality-threatening activities to at least 100 feet from a spring box, especially in the upslope position. Surface water draining into that area should be redirected and all activities limited within the drainage area. If livestock are present, use fencing to keep animals out of the drainage area.

Once the spring is developed and nearby sources of contamination are eliminated, it is important to disinfect the entire water system and then submit a water sample to a state-certified water-testing laboratory for water-quality analysis. If a water test indicates bacterial contamination, check the water supply location and construction of the system for potential pollution pathways. If improvements can be made, the system should then be shock chlorinated. After two weeks, have the water retested by a state-certified water-testing laboratory. If the water again tests positive for bacterial contamination, you have the option of finding a new source of water or installing a continuous disinfection system, such as an ultraviolet light. Most springs used for drinking water require some type of continuous disinfection system to make certain that the water is safe for consumption. For more information on treating water supplies containing coliform bacteria, consult Chapter 5.

Drinking Water from Roadside Springs

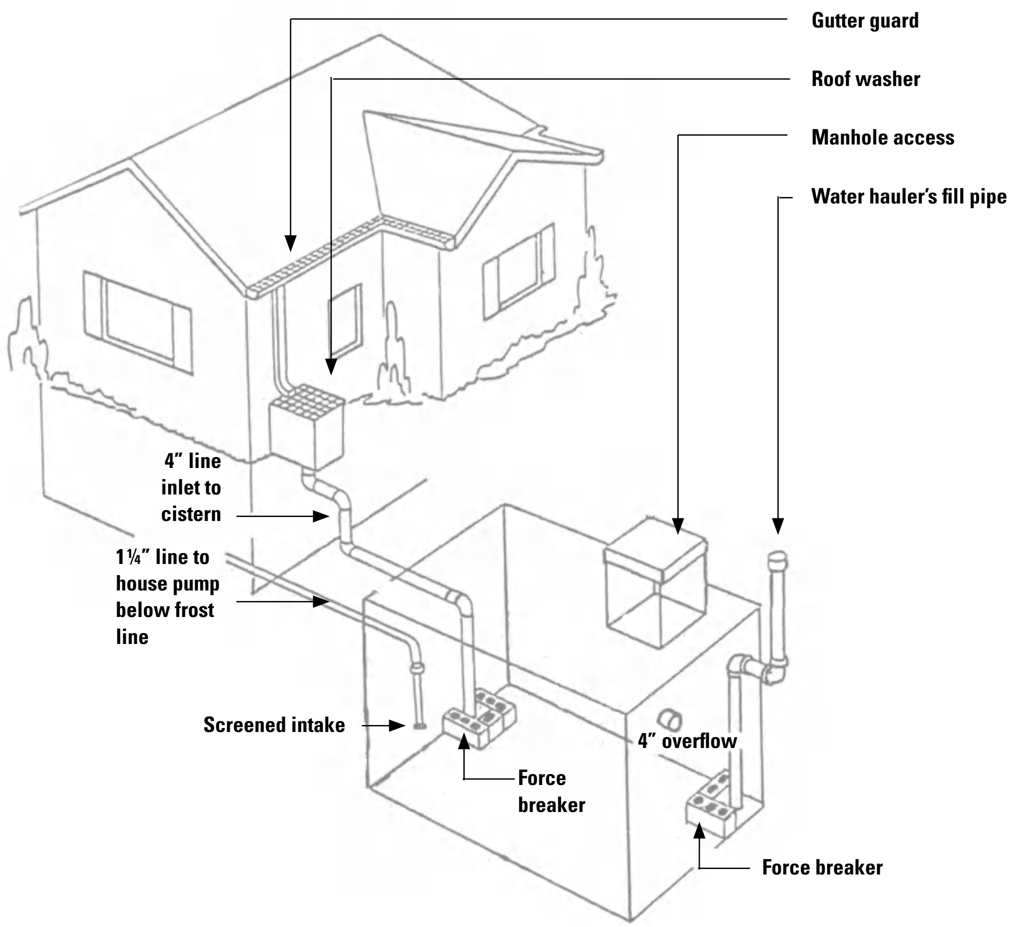
In Pennsylvania it is not uncommon for rural residents to use roadside springs for drinking water. It's important to understand, however, that roadside springs are just as vulnerable to bacterial contamination as other privately owned springs. In fact, many roadside springs that are located on public property may already undergo disinfection to ensure that the source is safe for consumption. Any roadside spring that is being used as a drinking water supply should be tested for total coliform bacteria. These springs should only be used as a source of drinking water if they have been tested and found to be bacteria free. When it comes to your family's health and safety, never assume that a water supply is safe for drinking. Surveys conducted by Penn State researchers have found that more than 75 percent of untreated springs contain unsafe levels of bacteria.

RAINWATER CISTERNS

Roof-catchment cisterns are systems used to collect and store rainwater for household and other uses. Such systems consist basically of a house roof, or catchment, and a storage tank or cistern. A system of gutters and downspouts directs the rainwater collected by the roof to the storage cistern. The cistern, typically located underground, may be constructed of various materials including cinderblock, reinforced concrete, or precast concrete, fiberglass, or steel. The cistern supplies water to the household through a standard pressurized plumbing system. A typical arrangement for a roof-catchment system is shown in Figure 2.9.

Current use of rainwater cisterns may be increasing. Those who live in areas where groundwater and surface water are unobtainable or unsuitable for use have been compelled to resort to cisterns as sources of water. Rainwater collection on a household scale is quite practical in areas where there is adequate rainfall and other acceptable sources of water are lacking. The coal strip-mining region of western Pennsylvania is one such area. Mining has rendered much of the

Figure 2.9. Typical roof-catchment cistern system.



ground and surface water unfit for drinking and other uses in large portions of these areas. Rural residents, forced to find other sources of water, have invariably turned to roof-catchment cisterns.

Roof-catchment cisterns may also be used to supply water to farms. Watering troughs and rain barrels can be filled by water collected from barn and other outbuilding roofs. A storage cistern built alongside a barn or other building could serve as an emergency source of water for firefighting in the event that a pond was not nearby. However, the use of rainwater for supplying domestic water needs is not without its problems.

Water-quality is of concern, especially when the rainwater is to be used for drinking in addition to other domestic uses. Rainwater and atmospheric dust collected by roof catchments contain certain contaminants that may pose a health threat to those consuming the water. Lead and other pollutants may accumulate in cistern bottom sediments; and untreated rainwater is quite corrosive to plumbing systems. Measures must be taken to minimize these and other water-quality problems in cistern systems. Recommendations for doing this are presented below, as well as guidelines for designing and building roof-catchment cistern systems.

Cistern Design

The storage capacity of a rainwater cistern depends on several factors:

- the amount of rainfall available for use
- the roof-catchment area available for collecting that rainfall
- the daily water requirements of the household
- available money supply

All but the first of these factors can be controlled to some extent by the cistern owner.

Available Rainfall

Across most of Pennsylvania, annual rainfall averages around 40 inches. During drought years there may be as little as 30 inches, while excessively wet years may produce 50 or more inches of rainfall. For most planning purposes the average figure should be used, although designing a cistern based on the lowest figure would guarantee enough storage to get you through even the driest years.

Owing to evaporative and roof-washer losses (to be discussed later), only about two-thirds of the annual total rainfall is actually available for cistern storage.

Daily Water Needs

The amount of water you design your roof-catchment cistern to collect and store depends on your daily water needs. If you have a small catchment area and a low-volume cistern, then your water use will be limited accordingly. So it is important when designing a roof-catchment cistern system to have some idea how much water you will require from it every day.

Various estimates of household water use have been published. The average base use determined by water utilities is 7,500 gallons per month, which is equivalent to an average yearly minimum need of 90,000 gallons per household. Common household planning provides for 50 to 75 gallons a day per person, or 73,000 to 110,000 gallons a year for a family of four. One-third to one-half of this amount is used for flushing toilets. However, those who must rely solely on rainwater-fed supplies will undoubtedly use less water.

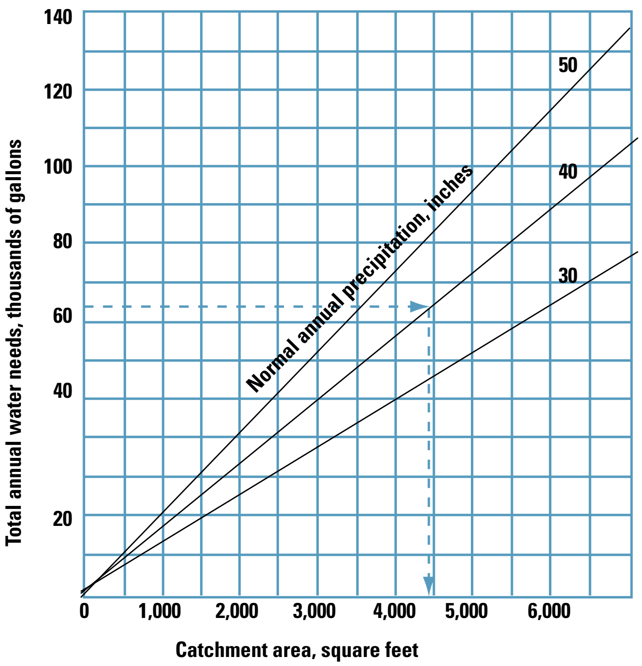
It should be clear from this brief discussion of water use that there is considerable variation, depending on the circumstances. For purposes of general cistern design, the figure 50 gallons a day per person is probably the best one to use. This figure would be applicable for a family living in a home with hot and cold running water and all the modern conveniences (including automatic washer and dishwasher), and no special water conservation measures. The installation of water-saving devices could considerably reduce household water use with no conscious effort on the part of family members. Additional information on water conservation in the home can be found in Chapter 6.

Catchment Area

The roof area to be used as the collection surface is usually predetermined by the size of the existing house or other outbuilding roofs. However, when planning a rainwater collection system from the ground up, where the size of the catchment is to be designed to suit domestic water needs, the following guidelines will be useful.

Figure 2.10 allows the catchment area required to be determined based on annual water needs and annual precipitation. As an example, suppose the average annual precipitation for your area is 40 inches. You have determined that your family of four requires 200 gallons a day or 73,000 gallons annually. From Figure 2.10 the needed catchment area is determined to be 4,400 square feet. (Note: Roof area can be determined by measuring the outside of the building or buildings to be used to collect rainfall. Do not measure the actual roof surface unless it is horizontal.)

Figure 2.10. Graph used to determine catchment area needed.



Cistern Size

A cistern should have sufficient storage capacity to carry the household through extended periods of low rainfall. A three-month supply of water, or one-fourth of the annual yield of the catchment area, is generally adequate in areas such as Pennsylvania where the rainfall is distributed fairly evenly over the course of the year. For example, if you have determined your annual domestic water needs to be 40,000 gallons (and most important, you have enough catchment area and annual precipitation to supply this amount of water), then you should design and build a cistern with a 10,000-gallon storage capacity.

A minimum storage capacity of 5,000 gallons is recommended for domestic cisterns. This capacity should eliminate having to buy or haul water, a practice that is not only inconvenient but can become somewhat costly. Remember these words of wisdom when designing your roof-catchment cistern: "You pay for a large cistern once and a small one forever."

Cistern Construction

Location

Cisterns should be located as close as possible to the house or wherever the water is to be used. They may be built above or below ground, but below-ground cisterns are recommended in this part of the country to avoid freezing during the winter months. Underground cisterns also have the advantage of providing relatively cool water even during the warmest months of the year. Cisterns may be incorporated into building structures, such as in basements or under porches. This way you can use foundation walls for structural support as well as for containment of stored rainwater.

A cistern should be located where the surrounding area can be graded to provide good drainage of surface water away from the cistern. Avoid placing cisterns in low areas subject to flooding. Both of the above steps will reduce the chance of storm runoff contaminating the stored cistern water.

Cisterns should always be located upslope from any sewage disposal facilities; at least 10 feet away from watertight sewer lines and drains, at least 50 feet away from non-watertight sewer lines and drains, septic tanks, sewage absorption fields, vault privies, and animal stables, and at least 100 feet away from sewage cesspools and leaching privies. It pays to check these things out carefully before turning the first shovelful of earth for the cistern excavation.

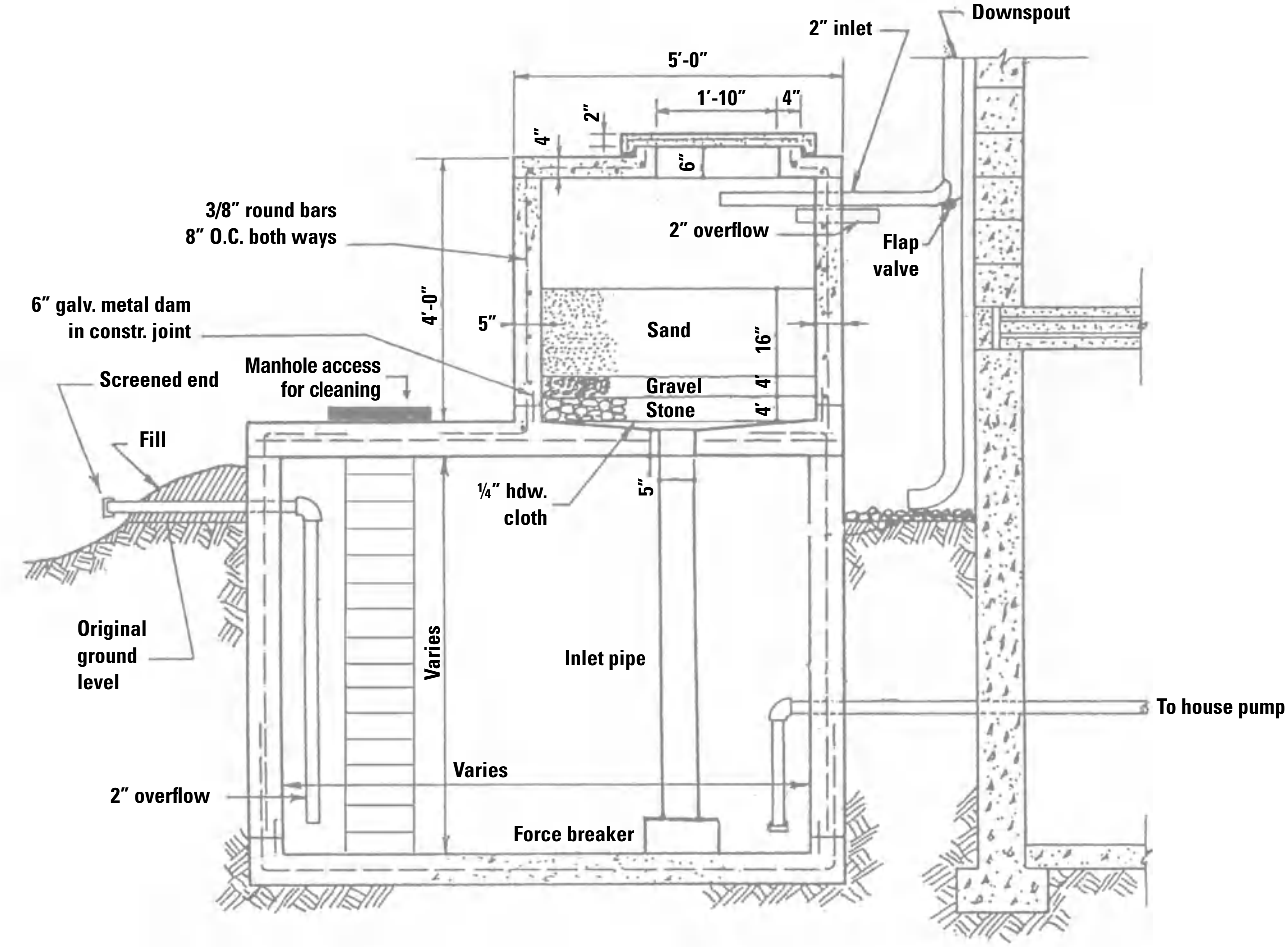
In certain situations, such as a barn or other outbuilding roof that supplies collected rainwater to a house downslope, cisterns may be located so as to provide gravity flow to the place of use. This setup is definitely preferable if it can be worked into your particular system. In most cases, however, the level of water stored in underground cisterns is lower than the points of use within the distribution system, so a pump and pressurized system are usually required.

Construction

Cisterns can be constructed from a variety of materials, including cast-in-place reinforced concrete, cinderblock and concrete, brick or stone set with mortar and plastered with cement on the inside, ready-made steel tanks, precast concrete tanks, redwood tanks, and fiberglass. Cast-in-place reinforced concrete is considered the best, especially for underground cisterns. However, cinderblock-walled cisterns with concrete floors are common and quite satisfactory for below-ground construction; these are usually somewhat less expensive than the all-concrete version. Concrete walls and floors should be at least 6 inches thick and reinforced with steel rods.

A general plan for a below-ground concrete cistern is shown in Figure 2.11. If cinderblock or concrete block is used for the walls of the cistern, all hollow cores should be filled with concrete and reinforced rods should be placed vertically to add strength to the structure. Footers may be necessary for larger cisterns. Footing drains should be installed around the perimeter of the cistern and drained to daylight. This reduces the chances of contaminating cistern water from the outside and also prevents the possibility of saturated soil providing an excessive horizontal load against the cistern walls.

Figure 2.11. Cross-section of a concrete cistern with filter (not to scale).



The top of the cistern should be reinforced concrete and should fit tightly onto the rest of the structure. The top may consist of individual panels or it may be a one-piece slab. In any event, a manhole through the top of the cistern to allow access to the storage tank should be included. Such an opening should be at least 2 feet across. A heavy concrete or iron lid should be fitted tightly over the opening to prevent the entrance of light, dust, surface water, insects, and animals.

Manhole openings should have a watertight curb with edges projecting several inches above the level of the surrounding surface. The edges of the manhole cover should overlap the curb and project downward a minimum of 2 inches. Manhole covers should be provided with locks to further reduce danger of contamination and accidents.

Place the manhole opening near a corner or an edge of the structure so that a ladder can be lowered into the cistern and braced securely against a wall. The access is necessary for the periodic maintenance tasks, to be discussed later. An alternative is to build concrete steps and handholds into the cistern wall beneath the opening.

The interior walls and floor of the cistern should be smooth to make cleaning easier. A cement plaster can be spread over the interior, depending on how rough the basic construction is. Cement-based sealants, such as Thoroseal and Sure-Wall, can be applied to the interior as well, to provide a smoother finish and further protection against leakage. A cistern that leaks is useless, but it is dangerous as well; if stored water can leak out, contaminated surface and groundwater can leak in. It is worth the time when building a cistern to do it right—get a good builder who will guarantee his work against leakage.

Vinyl liners may be used to prevent leakage in some cisterns, but they are usually troublesome. They are expensive and prone to puncture, and they prevent the use of cleanout drains and other accessories inside the cistern. Try a vinyl liner only as a last resort when all other efforts to prevent leakage have failed.

Another important feature of a well-designed cistern is an overflow pipe or pipes. The overflow can be in the form of a standpipe that leads through the floor of the cistern to a drain. Such an overflow pipe, or any other cistern outlet for that matter, should never be connected to a sewer line, either directly or indirectly. The drain line can also lead to a free outlet downslope from the cistern. The diameter of the overflow pipe should be at least as large as the diameter of the inflow pipe from the roof catchment.

The outside end of an overflow pipe should be effectively screened using a fine mesh rust-proof screening to prevent the entrance of animals and insects. The screening can be cut to a size large enough to be wrapped over the end of the overflow pipe and should be secured with a hose clamp or similar fastening device.

Large-diameter plastic pipe should be used for the overflow pipe in any case. When designing overflow outlets, it's important to provide good drainage away from the cistern and house.

A cleanout drain is also a key feature that allows the cistern to be drained for periodic cleaning and maintenance. A cistern without a drain has to be pumped out before any maintenance or cleaning can be done.

A cleanout drain should lead to a free outlet and never a sewer line. The floor of the cistern should be sloped slightly toward the drain for ease of cleaning. A valve to open and close the drain should be controlled from above ground level. The valve and drain line should be insulated by a sufficient depth of earth to prevent freezing during even the most severe winter weather.

The cleanout drain line needs to be at least 3 or 4 inches in diameter to avoid clogging—a large amount of sediment may have to move through the line during cleaning operations. The outlet should be located where draining water will not cause any problems or complaints from neighbors.

Cisterns should be vented to allow fresh air to circulate into the storage compartment. One or more large diameter pipes through the top of the cistern will serve this purpose. The outside opening of each pipe should be screened in the same manner as that described above for overflow pipes. The openings, located several feet above the ground level, should face the direction of the prevailing winds, west in most cases, to maximize ventilation. Four or six-inch diameter plastic pipe is good for vents. Make sure there is a watertight seal where each vent pipe goes through the top of the cistern.

The water line from the cistern to the house or other place of use should be buried below the frost line and should be 1 or 1¼ inches in diameter. The intake head should be effectively screened and elevated a minimum of one foot above the floor of the cistern to prevent sediment from being drawn into the distribution system. The portion of the intake pipe within the cistern should be plastic. The best position for the intake is on the opposite side of the cistern from the roof-water input pipe.

A separate input pipe for adding hauled water is another important feature of the well-designed cistern. Where possible, it is best to locate the above-ground portion of the fill pipe near the driveway or other road surface, so that the water truck does not have to drive over your lawn to reach it. Four-inch plastic pipe makes a good fill pipe. Place a tight-fitting cap over the above-ground end of the pipe. You may want to padlock the cap to further reduce the possibility of contamination.

Water entering the cistern with any kind of force behind it, as during a summer thundershower, or from a water truck, tends to agitate the stored water and possibly stir up sediment unless steps are taken to lower the force of the incoming water. One way of doing this is through the use of "force breakers."

Water entering the cistern from either the roof or a water truck should travel down a 4-inch plastic pipe into a force breaker box made from concrete blocks. The blocks should be set in mortar on the floor of the cistern with the cavities facing up. Slots or openings with an area of at least 13 square inches need to be cut into the lower end of the pipe to allow the incoming water to move from the pipe to the cistern. Force breakers should be installed under both roof-water and water-hauler inlets.

Roof Washers

Several other very important construction features will help ensure good-quality cistern water. Roof washers and roof-water filters were mentioned earlier, and their importance and construction details are discussed here.

A lot of dirt and dust collects on the roof-catchment surface between rainstorms. This debris can include particles of lead and other atmospheric pollutants as well as bird droppings. These contaminants will enter the cistern along with the roof water unless steps are taken to prevent contamination. The use of roof washers and roof-water filters can reduce the amounts of these contaminants entering the system.

The first water to come off the roof at the beginning of the rainstorm is the most contaminated. The degree of contamination will depend on several things including the length of time since the last rainfall, proximity of the catchment to a highway or other local source of airborne pollution, and the local bird population. Also, certain types of materials are preferable for the catchment surface, as will be detailed later.

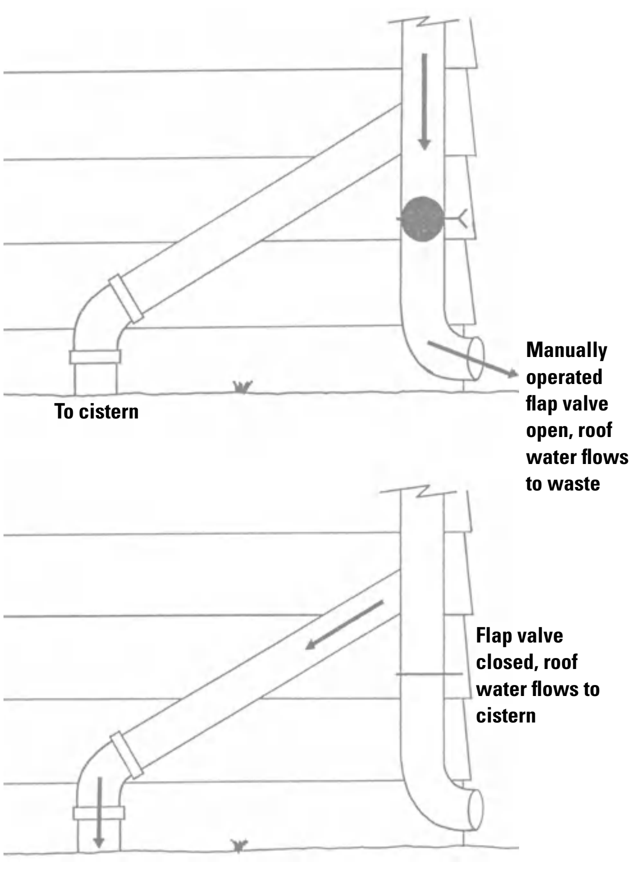
A roof washer is a mechanism that diverts this initial highly contaminated roof water away from the cistern. Once the catchment surface has been washed off by an adequate amount of rainfall, the roof water is once again routed to the cistern for storage. Usually the first 0.01 inch of rainfall is considered adequate to remove most of the dust and dirt from the surface of the catchment. In this way, only the cleanest roof water is collected in the cistern, whereas the contaminated roof wash is discharged to waste.

There are several ways of accomplishing this objective. The roof water can be diverted manually through a series of valves within the spouting system, or automatic roof washers may be fabricated by the cistern owner or purchased from commercial distributors.

A simple roof-wash diverter is shown in Figure 2.12. This particular design requires manual operation of a flap valve to control the flow path of the roof water within the spouting system. Such a valve would be necessary on each downspout unless they all converged into a single pipe just before emptying into the cistern. The single-valve arrangement is definitely preferred since the operation of this type of diverter requires that someone go out and close the valve shortly after the rain begins, allowing the roof water to flow into the cistern. The valve should be located so that it can be reached or controlled from a covered porch or other roofed area adjacent to the house or cistern.

During periods when rains are separated by only brief periods of time (less than a day), it is not necessary to divert the initial roof wash every time it begins to rain. However, it is important to divert the initial roof water produced by the first rainfall following an extended dry period. This requires returning the diverter to the rinse position following each storm to ensure that dirty water isn't accidentally added to the cistern.

Figure 2.12. A simple roof-wash diverter.



Determining how much roof water to allow to run to waste before routing it to the cistern will vary for each storm. You can use the visual appearance of the roof water as an indicator—if to your eye it runs clear when collected in a clear glass jar, you can direct the water to the cistern for storage and subsequent use. Or you can place a large 10- to 20-gallon container under the downspout draining to waste. The container should be sized to suit your particular roof area—10 gallons per 1,000 square feet of roof area.

At the beginning of a rainstorm, then, the dirty roof water is directed into the container, and when it is full you know that the catchment has been sufficiently rinsed and the roof water can thereafter be routed to the cistern. For this type of arrangement, a single roof-water collection vessel for the entire catchment is best. Adequate drainage, such as into a gravel-filled hole (well removed from the cistern), should be provided for the roof water that is to be wasted, whether or not it passes through a collection vessel first.

There are also automatic roof-wash diverters that do not require someone's presence to operate at the start of a rainstorm. The basic principle is the same. A certain quantity of contaminated roof water at the beginning of a rainstorm is collected in a vessel so that it cannot enter the cistern. Once the catchment has been rinsed off by a sufficient quantity of water, the roof water is again routed to the cistern. As with manual systems these should be inspected after each storm to ensure they perform properly during the next storm.

Roof-water filters

In addition to roof washers, your roof-catchment system should include a roof-water filter located between the catchment and cistern. Such a filter serves primarily to remove gross particulates and associated contaminants from the water before it enters the cistern. It can also serve to neutralize the acidic rainwater to some extent if limestone is used for the gravel and stone portions of the filter.

One possible design for a roof-water filter is pictured in Figure 2.11. The filter box can be totally or partially buried underground to lessen the chances of freezing during the winter months. The filter box shown in Figure 2.11 is made of reinforced concrete with walls and top a minimum of 4 inches thick. A short section of precast concrete culvert pipe can also function as a filter box; a lid or top is required, however. A manhole and cover similar to that described previously for the cistern itself should also be built into the top of the filter box to provide access for periodic inspection and maintenance. If the filter box is positioned directly on top of the cistern, as shown in Figure 2.11, be certain that there is a watertight seal where they join.

Several layers of gravel and sand make up the filtering medium. The total thickness of the filtering materials should be a minimum of 12 inches and a practical maximum of around 3 feet, depending on the area of the catchment and the size of the filter box. A filter the size of that shown in Figure 2.11 is adequate for a roof area of up to 2,000 square feet for all but perhaps the most intense rainfalls. For this reason, an overflow should also be built into the filter box, as shown in Figure 2.11. Mesh hardware cloth (¼ to ½ inch) or aluminum screening is placed on the bottom of the filter box (on the inside) before the gravel and sand are added. This keeps the filtering material in place. Also keep in mind that clean sand and gravel must be used, and the entire filter box should be cleaned and disinfected with chlorine.

A perforated splash plate should be located approximately 2 inches above the top of the sand. This serves to break the force of the incoming water, spreading it evenly over the top of the filter sand. In this way the sand is disturbed as little as possible. A nonmetallic material such as wood or plastic should be used as a splash plate. Half-inch holes should be drilled through the splash plate on 2-inch centers. Supports for the splash plate should be built into the wall of the filter box, thus allowing for easy removal and refitting of the plate for inspection and maintenance of the filter.

Any filter tends to clog over time and requires periodic maintenance. This may entail removing portions of the filter medium and replacing them with new sand or gravel. Whenever such replacement is necessary, the entire filter box should be cleaned and disinfected following the procedure described earlier. Periodic inspection of the roof-water filter in your system should provide visual evidence of a malfunction or clogged condition requiring remedial action.

Roof catchments

As mentioned previously, certain types of roofing materials are more suitable than others for use as collection surfaces for rainwater cisterns. Those most suitable for catchments are asphalt shingle, slate, and sheet metal (tin or aluminum). Consider the following factors when planning a roof-catchment cistern system:

- Rough-surfaced roofing materials collect dirt and debris, which will affect the quality of the runoff.
- Some painted surfaces, some wood shingles, and some asphalt shingles may impart objectionable tastes or colors.
- All gutters and downspouts should be easy to clean and inspect.
- The roof area should be large enough to supply the amount of water needed.
- The atmosphere in your area may contain undesirable or harmful pollutants that might affect the quality of collected rainwater.
- Before using a roof coating, consult local health authorities concerning possible toxicity of the material.
- The National Sanitation Foundation (NSF) has established a certification for materials used in water collection systems. NSF provides this listing of roofing materials on its web site at www.nsf.org (search their site for "Rainwater Collection" to find the listing).

Gutter guards should also be installed along any roof catchment. Aluminum screening of ¼-inch or ½-inch mesh hardware cloth can be cut into strips and secured over the top of open gutters. Gutter guards will keep leaves, twigs, and animals out but let water in. Also remove any tree limbs overhanging the catchment. You may also want to remove nearby trees that contribute leaves and twigs to the catchment; or, if you're planning a new home and cistern system, don't plant trees right next to the house.

Treating Cistern Water

Several of the design features described previously will help ensure good-quality cistern water. These include roof washers, roof-water filters, gutter guards, water force breakers, and effectively screened cistern inlets and outlets. In addition to these measures, however, specific water treatment will be necessary to ensure safe, potable cistern water. Recommendations for disinfecting cistern water and minimizing corrosion and sediment transport within distribution systems is covered in the following sections.

Disinfecting cistern water

Scrub down the interior of the new cistern with a disinfecting solution of chlorine and water, as described for roof-water filter boxes. CAUTION: Make sure there is adequate ventilation while working inside the cistern because of the dangers of chlorine gas and lack of oxygen. Following the disinfecting operation and before filling with water, rinse down the cistern interior with clean water until the strong odor of chlorine is no longer present. A cistern should also be disinfected following cleaning or other maintenance that requires emptying the cistern.

To disinfect stored cistern water the simplest procedure is to add 5 percent chlorine bleach once a week, at a rate of one ounce per 200 gallons of stored water during dry periods, or one ounce for each 400 gallons of stored water during wet spells. If a chlorine taste develops in the water it may be reasonably safe to dose weekly with one ounce for each 400 gallons of stored water. If, due to the absence of occupants, water is not chlorinated for a week or longer, one ounce of chlorine bleach for each 200 gallons of stored water should be added to the cistern when the occupants return.

You can devise a simple way of measuring the volume of water stored in your cistern. Obtain a wooden pole, long enough to reach the bottom of the cistern through the manhole opening. The pole can then be calibrated such that when it rests on the bottom it will indicate the approximate volume of stored water from the depth of the water. This can be done in the following way. First, find the capacity of the cistern by multiplying the length by the width by the depth (all in feet) to get the number of cubic feet of storage. Then multiply this figure by 7.5 to get the number of gallons of storage capacity. For example, a cistern measuring 10 feet by 8 feet, with a depth of 6 feet, would have a storage capacity equal to (10 X 8 X 6) X 7.5, or 3,600 gallons.

Once you have determined your cistern's capacity, you can calibrate the pole according to the following example. To calibrate a measuring pole for a cistern measuring 10 feet by 8 feet, with a depth of 6 feet, first divide the capacity by the depth in inches to obtain the number of gallons per each 1-inch thick layer of stored water (3,600/72 or 50 gallons in this example). Then simply mark the pole at 1-inch intervals, starting at one end and going toward the other until the total depth of the stored water is reached (6 feet or 72 inches in this example). At each 1-inch interval mark the corresponding volume, starting (at the bottom) with 50, 100, 150, 200, etc., adding 50 (for this example) to each successive interval.

Once calibrated, such a measuring stick gives you a quick way to estimate the volume of water remaining in the cistern at any given time. Depths and corresponding volumes also can be listed side by side in a simple table, and the stick is then only used to measure the depth of water in the cistern. Chlorine dosage required can also be listed alongside the various volumes for quick reference.

If the water has a disagreeable taste and odor, add 2 ounces of crystallized sodium thiosulfate (available from Fisher Scientific or other supply houses) to 1 gallon of clean water. Then add 1 quart of this solution to each 1,000 gallons of water in the cistern, mixing it with the cistern water but being careful not to stir up bottom sediment. After a few hours the water should be free of the disagreeable taste and odor.

Any water supply should be tested for bacterial contamination at least once a year. If a water analysis shows that the water is contaminated, a careful examination of the entire water supply system and of the area surrounding the cistern has to be made in order to find and eliminate the source of contamination.

As an alternative to adding disinfectant directly to the cistern, commercially distributed in-line automatic chlorinators and ultraviolet lights are available from most distributors of water-conditioning equipment.

Minimizing corrosion within cistern water systems

As pointed out previously, rainwater is acidic and therefore corrosive. Unless steps are taken to neutralize this water, it will corrode household distribution systems and add toxic metals such as lead and copper to the tapwater. Corrosion processes are very complex chemical reactions that involve many different factors. Following the recommendations presented here will not completely eliminate corrosion within your cistern system but should reduce it to tolerable levels.

Perhaps the surest way of minimizing tapwater metals is to use plastic pipe to service at least one cold-water tap within the system. This would effectively replace the source of metallic lead and copper (lead-soldered copper systems) with a nontoxic, noncorrodible conduit of PVC plastic. Be sure to use plastic pipe that meets specifications for conveying drinking water, if that is what you intend to use it for. If just one cold-water tap within your household were to be serviced by an all-plastic water line, then you should draw all of your drinking water from the tap and from no other. It would probably be best to plumb the kitchen cold-water tap and perhaps a bathroom lavatory with plastic. If you are planning a new system from scratch, then you may want to consider using plastic plumbing throughout the entire distribution system.

If your existing distribution system is composed of lead-soldered copper plumbing throughout, and you do not want to replace a portion of it with plastic, an alternative is to install an in-line acid neutralizer to reduce the water's corrosivity. Such units are available commercially from water treatment equipment distributors located throughout Pennsylvania. The acid-neutralizing units are in the $1,000 price range and are available in either manual or automatic models.

In lieu of an in-line acid neutralizer, a neutralizing agent can be added directly to the cistern. It would be necessary to add the appropriate amount of neutralizing agent at periodic intervals, depending on the amount and frequency of rainwater input to the cistern. For example, approximately 2 ounces of pulverized limestone can be added to each 1,000 gallons of rainwater to neutralize the acidity. Perhaps the most convenient treatment procedure is to add the neutralizing agent when you add disinfectant to the cistern (once a week), at least during weeks when additional rainfall is collected. During weeks when little or no fresh rainwater is collected, it would not be necessary to add more neutralizer to the cistern.

Some cistern owners place blocks of natural limestone in their cistern to serve as continuous neutralizing agents. We have no guidelines to offer you as to the size or other characteristics of such blocks.

Regardless of whether or not you install an acid neutralizer or plastic pipe, or add a neutralizing agent directly to the cistern, there is one simple thing that you should do before using the tapwater for drinking and cooking purposes. Always allow the cold water to run for about a minute before using it for drinking or cooking. This flushes the "stale" water (laden with metals if from lead-soldered copper or other metallic pipe) from the supply line, leaving you with tapwater of acceptable quality. This practice is especially important after a tap has gone unused for several hours, or overnight. Rather than just letting the water run down the drain during this procedure, you may use it for purposes other than drinking or cooking.

Minimizing sediment transport through cistern systems

Using roof washers and roof-water filters, described in detail earlier, minimizes the input of particulates or the formation of a sediment layer on the cistern bottom. Therefore, certain steps need to be taken to prevent this sediment from being transported through the distribution system and possibly reaching the tap.

Periodically cleaning the cistern to remove the sediment accumulation is recommended. This involves draining the cistern, scooping out the sediment, and washing down the interior with a brush and disinfectant. Before refilling the cistern, thoroughly rinse it with clean water. Such cleaning should be done at regular intervals every three to five years. Applying a new coat of interior sealant may also be necessary at the time of cleaning. Don't forget to set aside enough water to operate the household while the cistern is out of commission.

A simple, cartridge-style sediment filter should be installed between the cistern and tap to remove any sediment that might otherwise be transported to the tap.

Groundwater quality is a concern in many areas of the state. Contrary to popular belief, natural groundwater is not always free of pollutants and impurities. Some pollutants occur naturally when water interacts with impurities in the rock layers encompassing an aquifer (Figure 3.1). For example, hard water deposits from calcium and magnesium are common in groundwater from limestone aquifers, while hydrogen sulfide (which causes the rotten-egg odor), iron, and manganese often occur in certain sandstone and shale aquifers. Some aesthetic problems can cause additional drinking-water problems as well. Aggressive water from acidic sandstone and shale can cause the lead and copper to dissolve from household plumbing, leading to toxic concentrations capable of causing serious health effects in humans.

Human activities can also pollute groundwater aquifers. This pollution may originate from point sources (e.g., a pipe discharging into an aquifer) or, more often, from nonpoint sources (e.g., diffused flow from lawns, septic systems, and farm fields). Many groundwater pollutants from human activities cause adverse health effects (Figure 3.2). Coliform bacteria and *E. coli* bacteria commonly found in human or animal wastes can cause flulike illnesses if they are consumed in drinking water, while nitrates from fertilizers can cause blue-baby syndrome in infants. Also worth noting is that some of the naturally occurring pollutants discussed above, such as iron, manganese, and sulfate, can also come from mining or other human activities.

Figure 3.1. Frequency of pollutants causing aesthetic problems in private groundwater wells in Pennsylvania. *(From Sharpe et al. 1985; Swistock et al. 1993; Swistock et al. 2009)*

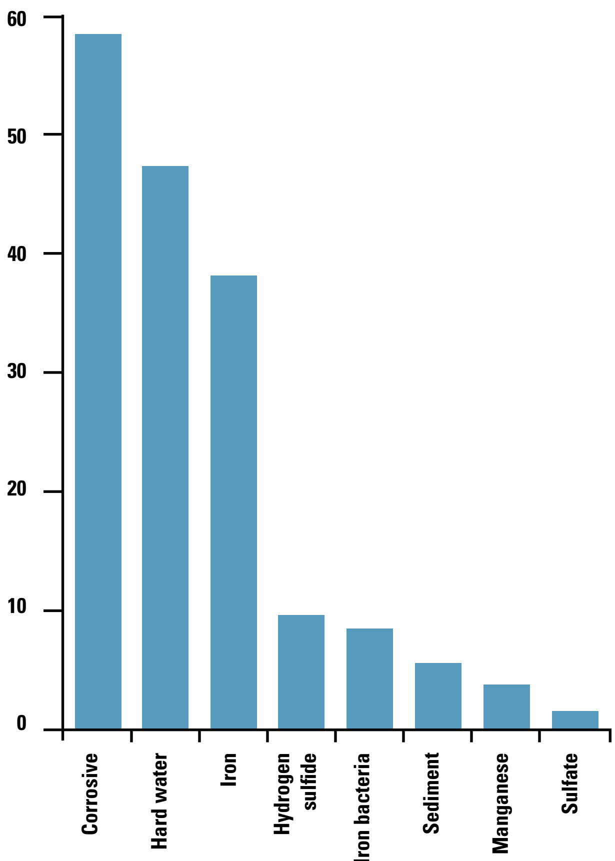
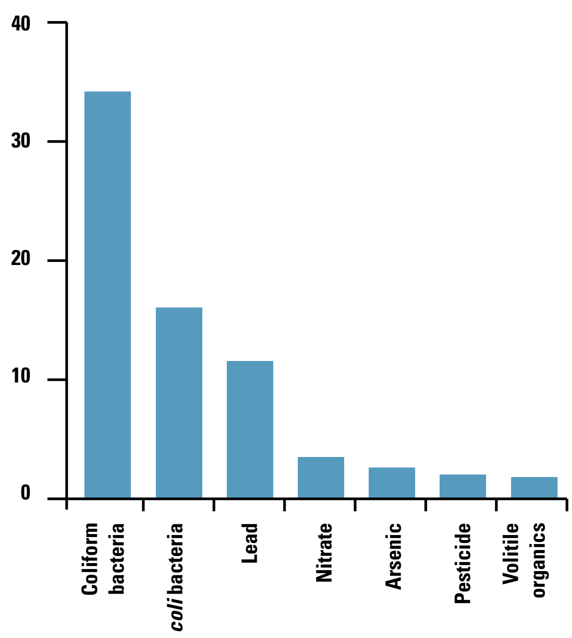


Figure 3.2. Frequency of various health-related pollutants in private groundwater wells throughout Pennsylvania. *(From Sharpe et al. 1985; Swistock et al. 1993; Swistock et al. 2009)*



WHAT CAN YOU DO TO PROTECT GROUNDWATER?

Some simple actions can help to ensure the future availability and health of Pennsylvania's groundwater resources:

- Do not apply fertilizers, herbicides, or other chemicals within 100 feet of wells or springs on your property. Reduce the use of these chemicals on other areas of your property.
- Use up household chemicals according to the label or dispose of them at hazardous waste drop-off locations rather than in the household garbage.
- Get your well or spring tested annually by a state-certified water-testing laboratory to detect local problems before they can contaminate the entire aquifer.
- Properly construct and maintain your on-lot septic system to prevent groundwater contamination.
- Properly seal any unused well that may exist on your property.

In Pennsylvania, many public water suppliers have developed wellhead protection programs to protect the areas of land that directly influence the quality of the local groundwater supply. It is the responsibility of each private water system owner to protect the land area that supplies water to his or her home drinking-water system. Groundwater is often polluted by the following activities:

- Improperly sealing unused wells
- Septic system malfunction or failure
- Gas or oil well drilling
- Illegal roadside dumps or improperly managed landfills
- Application of fertilizers, pesticides, herbicides, insecticides, and animal wastes
- Surface or deep coal mining
- Chemical spills from nearby industry
- Failing underground storage tanks
- Highway salt or salt storage piles
- Saltwater intrusion

This chapter explores the more common causes of human-made groundwater contamination affecting private water wells in Pennsylvania.

UNUSED WELLS

Many states have very specific water-well construction standards. Regulations often include a section ensuring that all unused wells be properly decommissioned by a certified professional. In Pennsylvania, guidelines exist only for public wells, but it is still very important that old unused wells be taken care of so they do not pose a hazard for those using the property and do not serve as a conduit for surface water to contaminate local groundwater resources. For more information on the proper procedures for sealing an unused well, refer to Chapter 2.

SEPTIC SYSTEM MALFUNCTION OR FAILURE

The 1990 U.S. census reported that one out of every four homes in Pennsylvania, or approximately 1.2 million homes, made use of an on-lot septic system for wastewater management. Homeowners who make use of both private water systems and on-lot septic systems should make certain that the distance between the two is adequate and that, ideally, the water supply is not downslope from the septic system or leach field. It is also very important that all on-lot septic systems receive proper routine maintenance to ensure that no system failures occur, which could affect the home's drinking water quality. A properly located and maintained on-lot system should pose no threat to a private drinking water supply.

In general, most on-lot septic systems treat wastewater in two stages, or sections. The first section consists of a septic tank (where solids are removed), and the second section consists of a soil absorption area (where liquids can percolate through the soil). As is true of a private water system, an on-lot septic system must be maintained periodically by the homeowner to ensure that it continues to function properly. Pennsylvania has regulations for the construction of new septic systems, but the maintenance schedule usually falls on the homeowner's shoulders. For this reason, many people do not maintain the system until there is a malfunction or complete failure.

If a septic system malfunction does occur, it could cause wastewater to back up into the house, pond on the land surfaces surrounding your seepage area, or discharge to groundwater, contaminating local water resources (including nearby wells and springs). To prevent this from happening, it is important for rural homeowners to conduct routine maintenance (assuming the system was designed and constructed properly).

How Do I Maintain My Septic System?

The easiest thing you can do to maintain your on-lot septic system properly is to conserve water used in and around the home. Septic systems function better with less water entering the system. In fact, a malfunction (hydraulic overload) can actually be caused by too much water entering the system. Installing water-conserving appliances and adopting simple water-conserving habits at home will help keep your system working properly.

Another key component of proper maintenance involves having your septic tank pumped out periodically. Most township ordinances and Penn State experts recommend pumping at least every 2-3 years. Pumping at this interval ensures that your system is cleaned out and ready to function the way that it was intended.

Other things that will help to keep your on-lot septic functioning properly include: (1) avoiding planting trees or removing roots in or near the soil absorption area, as they may interfere with the system, (2) not adding any chemicals or antibacterial agents to the system, and (3) avoiding the use of a garbage disposal.

For more information on on-lot septic systems, visit the Penn State Water Resources Extension Web site at water.cas.psu.edu or contact the Pennsylvania Septage Management Association at www.psma.net.

GAS WELL DRILLING

Gas well drilling has occurred for decades in much of western and northern Pennsylvania, with thousands of new and active gas wells in the state (Figure 3.3). Most of these wells tap gas reserves a few thousand feet below the earth's surface. With discoveries of new gas reserves in the Marcellus shale and new drilling technologies to reach previously untapped gas reserves, both the number and depth of gas wells are expected to rise dramatically over the next decade. As a result of renewed interest in gas drilling in Pennsylvania, a survey of private water well owners in the state during 2007 found that 13 percent felt that gas well drilling was the biggest threat to their water supply.

Potential Impacts on Private Water Supplies

Gas well drilling has the potential to cause occasional problems in both the quality and the quantity of water from nearby private water wells and springs. Gas wells produce polluted waste fluids from naturally occurring brines (water stored deep underground with high salt and metals concentrations). Newer drilling also relies on hydrofracturing, in which a mixture of water, sand, and chemicals is injected into the ground to fracture the rock and allow the escape of the tightly held methane gas. Hundreds of thousands of gallons of hydrofracturing fluids may return to the surface accompanied by new pollutants from deep underground. Pollution of private water supplies from gas well activity has been documented primarily from absent or corroded well casings on older or abandoned gas wells. Groundwater pollution has also occurred from flooded or leaking brine holding pits, accidental discharge of brines to the land surface, and spills of drilling chemicals and fuels at the drilling site.

Figure 3.3. A typical gas well site in McKean County, Pennsylvania.

Groundwater Pollutants from Gas Wells

Waste fluids from gas well drilling are highly mineralized and contain levels of some pollutants that are far above levels considered safe for drinking water supplies. As a result, even small amounts of brine pollution can result in significant impacts on drinking water supplies. The most common pollutants are salts (sodium and chloride) and various metals including iron, manganese, barium, and arsenic. Other pollutants associated with gas well waste fluids are specific conductance, alkalinity, total suspended solids (turbidity), hardness, calcium, magnesium, coliform bacteria, strontium, surfactants/detergents, sulfate, oil/grease, total organic carbon (TOC), and volatile organic compounds (VOCs) such as benzene.

A final problem that can be associated with gas drilling, or can occur naturally, is methane gas migration into water wells and springs. In this case, the methane gas rapidly escapes from the groundwater and may pose an explosion hazard in confined spaces. Methane in water usually creates obvious symptoms of effervescence and spurting faucets owing to gas buildup.

A study of 200 private water wells by Penn State and McKean County Cooperative Extension in 2007 found that 1 to 3 percent contained elevated levels of pollutants that could originate from gas drilling (see Figure 3.4). It is important to note that this study did not attempt to differentiate between effects from past versus current gas well drilling. Given the changes and strengthening of regulations on gas well drilling that occurred in the mid 1980s, it is likely that most of the groundwater contamination found in McKean County occurred from past drilling practices. Still, these results point to the importance of remaining vigilant in properly testing and monitoring private water supplies near gas wells using the strategies outlined later in this discussion.

Data from various regulatory agencies responsible for enforcing gas well drilling regulations indicate that more than 95 percent of complaints received by homeowners suspecting problems from recent nearby gas well drilling are, instead, due to preexisting problems or other land-use activities.

Strategies to Protect Water Supplies from Gas Drilling

State regulations are in place to minimize the impacts of gas drilling on water resources. There are setback distances that limit how close a gas well can be drilled to any water supply. Gas drilling companies must install a strong casing and cement (called the "freshwater protection string") to protect groundwater resources from contaminants moving through the gas well borehole. They must also collect waste fluids in plastic-lined pits and deliver the waste fluids to approved treatment facilities. Despite these protections, occasional problems still can occur.

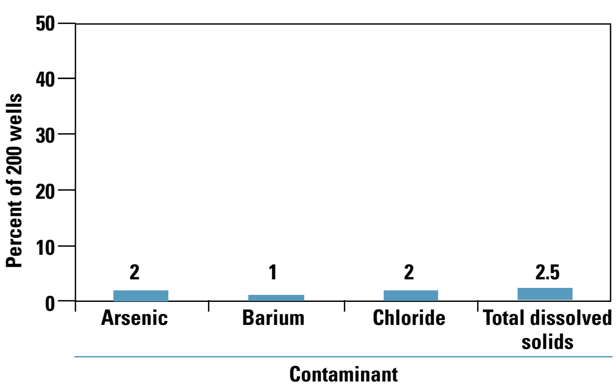
There are various steps you can take to protect your water supply from gas drilling impacts. These include:

- *Learn when and where drilling will occur*—Some homeowners learn of nearby gas well drilling plans through lease agreements or through required notification by certified mail if their water supply is within 1,000 feet of the proposed well. But anyone can be kept abreast of gas well drilling plans through the eNotice feature on the Pennsylvania Department of Environmental Protection (DEP) Web site. The eNotice provides permit information, but it requires a significant investment of time to learn.
- *Control seismic testing*—Before drilling wells in an area, gas companies often seek permission from land owners to do seismic testing to determine the thickness of gas-bearing rocks and other geologic information. If explosives are to be used in seismic testing, make sure to stipulate that each shot hole is promptly and properly decommissioned to prevent groundwater contamination by surface water. Also stipulate that explosives not be used within several hundred feet of a private water well or spring to ensure that water flow is not altered.
- *Get your water tested*—Before gas well drilling takes place, drinking water supplies within 1,000 feet of the proposed gas well will likely be tested at no charge to the homeowner by a certified testing laboratory hired by the gas company. Make sure to arrange to receive the results of this testing in a timely manner from the commercial laboratory. If your water supply is more than 1,000 feet from a proposed gas well site OR if you simply want to confirm the results collected during the predrill survey, you must arrange to have your water tested at your expense. It is always a good idea to have your own independent water analysis for comparison.

Remember that water samples to document impacts from gas well drilling generally should be collected by an unbiased, professional representative from a state-certified water-testing lab. This adds significantly to the cost of water testing but is vital for the admissibility of the results in any legal action related to polluted private water supplies. Most local state-certified water-testing labs provide specific gas drilling packages that include pollutants that can result from drilling activity. You can expect to pay $200 to $500 or more to have a predrilling water sample collected and analyzed by a certified water-testing laboratory, depending on the complexity of the test package. More information on water-testing strategies can be found in Chapter 4.

- *Pay attention to symptoms of problems*—During or after nearby gas well drilling, there may be obvious changes to your water supply that warrant filing a complaint to the Pennsylvania Department of Environmental Protection (DEP). Common symptoms include water foaming, muddiness, bubbling, spurting faucets, metallic or salty taste, fuel or oil smell, and a reduction in water flow. Should you notice any obvious changes in your water supply in conjunction with nearby gas well drilling, you can file a complaint with the regional DEP office. They will investigate the claim within 10 days and make a determination of the cause within 45 days. Complaints filed during gas well drilling operations or within six months after drilling is completed place the burden of proof on the gas well operator. Complaints filed more than six months after drilling has ended place the burden of proof on the homeowner. During the investigation, DEP will obtain results from all predrilling water testing. They may also decide to collect additional water samples as part of the investigation.

Figure 3.4. The percentage of 200 private water wells in McKean County, Pennsylvania, that failed drinking water standards for come common pollutants associated with gas well drilling. *(Clark et al. 2007)*



- *Document well and spring flow before drilling*—Diminished or lost water supplies resulting from gas well drilling have occurred but are rare. When this does happen, it is usually an obvious, complete loss of water rather than a subtle decrease in water yield. Well and spring owners who wish to document water supply conditions before and after gas well activities need to hire a professional water well contractor or hydrogeologist to measure and document these conditions independently. You can find a list of local water well contractors certified by the National Ground Water Association (NGWA) at www.wellowner.org.
- *Include water resource protection in your lease*—Many of the aforementioned ideas for protecting a water supply can be stipulated in a gas leasing agreement (if a lease is offered by the gas company). The lease agreement allows a homeowner to set rules for the gas company to follow in order to access private property. For example, you can stipulate setback distances, water testing, or flow measurement in your lease agreement.

More information on gas well drilling can be found at www.depweb.state.pa.us; choose keywords, "Oil and Gas."

ROADSIDE DUMPS

Unfortunately, in rural areas throughout Pennsylvania, illegal roadside dumps exist. These provide a cheap and easy way for individuals to dispose of appliances, furniture, hazardous materials, and other trash. Although convenient for the homeowner, such a dump is an eyesore as well as a hazard for those enjoying our natural areas and can often negatively affect local surface and groundwater quality.

Landfills exist for the disposal of waste materials in a way that poses minimal risk to the environment. When roadside dumps are used out of convenience, there is no way of knowing if or when hazardous materials could leach into nearby surface or groundwater supplies.

If you know of or can see an illegal roadside dump close to your home and you are on a private water supply, make sure to test your water regularly to monitor for possible contaminants entering your water supply. Knowing what to test for can be difficult since the contamination is based on the materials being dumped. If you have an idea of the contents of the dump, you can use that to determine what water tests would be most appropriate. More information on roadside dumps and water quality can be found at pubs.cas.psu.edu/FreePubs/pdfs/UB040.pdf.

AGRICULTURE

Agriculture is one of our most important industries; however, many of the practices associated with agricultural operations can affect groundwater quality. Removing plant cover from the soil can cause erosion. Nutrients, sediment, pathogens, and residues from pesticides or fertilizers can run off into streams or enter groundwater. While the agricultural industry and small farmers do not intentionally pollute our surface and groundwater supplies, such pollutants can end up in private water systems.

It is often not easy for a homeowner to pinpoint the source of contamination from nearby agricultural operations. If you suspect that your drinking water is being affected by a nearby farm, try contacting the landowner to see if he or she can give you information about what chemicals are used on the farm. This will help you select the appropriate water tests.

In general, private well water potentially affected by agricultural activities should be tested regularly for total coliform bacteria, *E. coli,* and nitrates. If you can obtain information about which specific pesticide or fertilizers were used, these tests can be added.

MINING

Pennsylvania has a long history of mining. Mines were largely underground until the 1960s, when stripmining technology was developed to access minerals from the surface. Early coal mining regulations were lax, resulting in significant pollution of both surface and groundwater resources, especially in western Pennsylvania. In areas where coal mining has occurred, private water wells and springs may have acidic water that is contaminated with high levels of iron, manganese, aluminum, and sulfate. If you live in a mining region, you may notice poor-tasting water that causes various staining and odor problems as a result of nearby abandoned mines.

Strengthening of mining regulations during the 1970s included protections for private water supplies near active mining sites. These regulations include a requirement that, in certain cases, water supplies proven to be contaminated by active mining be replaced. If you are concerned about historic or proposed mining in your area, consider having your water tested for pH, sulfate, iron, manganese, and aluminum.

WATER-TESTING BASICS

If you've had your water tested, you probably did so to find out if it is safe for drinking. Even if your water tastes, smells, and looks fine, water testing is necessary because many contaminants have no obvious odors or tastes. In other cases, where a water-quality problem is obvious, testing can determine the exact concentration of the pollutant to assist in determining the best solution to the problem.

Water testing is especially necessary if your house is served by a private water system, because some of these systems have water-quality issues. Private water systems include drilled wells, dug wells, springs, or cisterns that serve an individual home. There are no regulations or laws requiring water testing, system maintenance, or water treatment for these water supplies. Rather, owners must voluntarily arrange for water testing and must voluntarily correct any problems to provide safe drinking water. Regardless of whether your water supply is private or public, the information in this chapter will help you interpret water test results.

If you live in a community served by a public water supply (i.e., one source of water for multiple customers), then the water company already does water testing for you. Public water suppliers are required by law to routinely test their water and treat it to meet water-quality standards. They are also required to issue water test reports to their customers on a regular basis. This chapter may be helpful in interpreting these reports as well.

Although drinking water standards are applicable to all types of water supplies, they are not legally binding for private water supplies. It is recommended, however, that private water supply owners maintain their water quality by the same standards required by law for public water supplies.

Why Test Your Drinking Water?

More than one million homes in Pennsylvania are served by private water supplies (wells, springs, or cisterns). Homeowners with this type of water supply should consider having it tested for the following reasons:

1. Unlike public water systems, private water supply testing is the homeowner's voluntary responsibility. No government agencies or programs routinely test private water systems for homeowners.
2. Surveys indicate that about half of private water supplies have never been tested by a state-certified laboratory.
3. Additional studies have found that about 50 percent of private water systems fail at least one drinking water standard. In fact, surveys have shown that only about 20 percent of homeowners with unsafe drinking water are aware of the problem.
4. Many pollutants found in private water systems have no obvious indicators (such as smell or taste) and can only be detected through laboratory testing.
5. Water testing is generally economical and convenient, with many testing laboratories located throughout the state.
6. Water testing provides vital information to document the quality of your drinking water. Data from previous tests may be necessary if you ever need to prove in court that a nearby land use has damaged your drinking water quality.
7. The only way homeowners can be certain that their water is safe to drink is to have the water tested periodically.

Tests to Have Done Routinely

While it is possible to have a water supply tested for many things, such tests are very expensive and often unnecessary. Instead, homeowners should focus testing on a few standard parameters along with additional tests related to nearby land uses.

Private water supplies should be tested every year for total coliform bacteria and *E. coli* bacteria. Bacteria are more likely to be present during wet weather conditions. For this reason, testing for total coliform every 14 months will ensure that the testing is done at different times of the year. Coliform bacteria includes a large group of many types of bacteria that occur throughout the environment. They are common in soil and surface water and may even occur on your skin. Large numbers of certain kinds of coliform bacteria can also be found in waste from humans and animals. Most types of coliform bacteria are harmless to humans, but some can cause mild illnesses and a few can lead to serious waterborne diseases.

If coliform bacteria are found in a water supply, a follow-up test can be done by the laboratory to look for *E. coli*—a type of coliform bacteria found only in human or animal wastes. A positive *E. coli* result is much more serious than coliform bacteria alone because it indicates that human or animal waste is entering the water supply.

Drinking water should be tested for pH and total dissolved solids (TDS) every three years. These tests are similar to a doctor taking your temperature—they are general tests that provide an index to the quality of your drinking water.

Water with a pH lower than 6.5 or greater than 8.5 can cause corrosion of lead and copper from household plumbing and bad tastes. The total dissolved solids (TDS) content of drinking water should be below 500 milligrams per liter (mg/L), and the value should not change much from one test to the next. Increases in the TDS of water could indicate that pollution has occurred, warranting further, more detailed, testing.

Additional Testing

Tests Related to Local Land Uses

Every three years, additional testing should be done related to land uses occurring or expected to occur within sight of the home. Pollutants associated with various common land-use activities in Pennsylvania are shown in Table 4.1. Keep in mind that not all laboratories are able to run all of these tests.

Tests Related to Obvious Symptoms

Sometimes obvious stains, tastes, or odors in water prompt a homeowner to seek water testing. Many pollutants that cause obvious aesthetic problems occur naturally in groundwater, but some can come from land uses, especially mining. While the presence of these pollutants is apparent from their symptoms, testing through a certified laboratory is valuable to confirm the pollutants and provide valuable information about their form and concentration. This information is helpful when determining the best options for treatment. Some common drinking water symptoms and their associated pollutants are given in Table 4.1.

Where to Test Your Drinking Water

Always have your water tested by a state-certified water-testing laboratory. The Pennsylvania Department of Environmental Protection (DEP) certifies water-testing laboratories in Pennsylvania to ensure they are using analytical procedures designed to give accurate test results. Be sure to ask if the lab is certified and what tests it is certified to perform every time you have your water tested. Laboratories are reevaluated periodically, and their certification status may change. You can obtain a list of certified labs from your county Penn State Cooperative Extension office, online at water.cas.psu.edu, or from your local DEP office. Also, your local DEP office can arrange for bacteria testing through the state DEP laboratory.

Be cautious of water test results from uncertified labs. In addition, be cautious of water test results from salespeople and others who say they have their own laboratories or who try to test water at your residence. Always have these tests confirmed by a certified laboratory and, if possible, interpreted by a knowledgeable and neutral third party before taking corrective action.

Once you have received your water test report from the laboratory, you're ready to interpret exactly what it means. The sample water test report shown in Figure 4.1 (page 38) will get you started by familiarizing you with the information presented in the report.

Table 4.1. Common drinking water problems and their symptoms (left) and land use causes (right).

Symptom	Test
Orange-brown stains, metallic taste	Iron, manganese
Black flecks or stains	Manganese, iron
White or gray film, increased soap use, damaged hot water heater	Hardness
Salty taste	Chloride
Blue-green stains, metallic taste, especially early in morning, small leaks in metal plumbing	pH, corrosivity index, copper, lead

Land use	Test
Mining	Iron, manganese, sulfate, aluminum
Gas or oil well drilling	Chloride, barium
Industry	Organic scans
Gas stations	Petroleum products
Road deicing	Sodium, chloride
Homes with septic	Nitrate, bacteria
Agriculture	Nitrate, pesticide scans

Collecting Water Samples

Who Should Collect Water Samples?

Homeowners can usually collect water samples themselves, after obtaining properly sanitized containers and instructions from the laboratory. Some rare, specialized tests, such as those for radon, *Giardia*, *Cryptosporidium*, and hydrogen sulfide, usually require that a lab employee visit your home to collect the sample.

In special circumstances where legal action could follow, it is best to have samples collected by an unbiased professional. For example, samples intended to document existing drinking water quality prior to mining, gas well drilling, or other land-use disturbances should be collected by a qualified third party. This adds to the cost of water testing but is vital for the admissibility of the results in any legal action related to polluted private water supplies.

Procedures

Most water samples are collected at the kitchen faucet since this is where most water is used for drinking and cooking. If you already have treatment equipment installed in your home, keep in mind that collecting a water sample from a kitchen or bathroom faucet is often influenced by the treatment equipment. If you are interested in determining the raw water quality from your well (as it emerges from the ground), you may wish to collect a sample before the water enters any water treatment equipment or the home plumbing.

Do not use food or drink containers to collect or take water samples to a laboratory! Instead, arrange to obtain properly sanitized containers and instructions from the laboratory ahead of time. The sample collection instructions provided by the laboratory must be followed carefully in order to ensure an accurate test result. In general, before taking the water sample, you should rinse the container two or three times with the water being collected. However, testing labs often supply containers that have a fixing compound preventing the loss or breakdown of a certain chemical. In this case, if the bottle is rinsed or allowed to overflow, the fixing agent will be removed. For this reason, read and follow sampling instructions carefully.

Special Instructions for Bacteria Samples

For bacteria testing, use a sterile container and clear all chlorine from the water system. Containers supplied by water-testing labs have a chemical present to remove any chlorine residual in the sample. Many labs recommend removing the aerator from the faucet and sterilizing the end of the faucet with a flame or rubbing alcohol before collecting the water sample.

Allow the water to run for a few minutes before collecting the water in the sample bottle. Remove the cap from the bottle, but take care to avoid contaminating the cap or the bottle. Do not set the cap down on anything, and do not touch the inside of the cap or the bottle with your hands. It is ideal to wear sterile plastic gloves when performing this procedure. Run water into the bottle, carefully secure the lid, keep the sample cool, and deliver it to the lab within 24 hours. For this specific test, the shorter the time elapsing between collection and analysis, the more reliable the results. Make sure you contact the lab to determine how and when the sample should be shipped or dropped off at the lab to ensure accurate results. Because of the time limits necessary for bacteria sampling, most labs will not accept water samples on Fridays or before holidays.

Special Instructions for Corrosion Samples

To test properly for corrosion, allow the water to stand in the pipes for at least 12 hours and collect a "first-draw" sample. This sample should be taken first thing in the morning before any water has been used. This collects water that has been in contact with the pipes for at least 12 hours and that is most likely to accumulate metals from corrosion.

COMPONENTS OF A TYPICAL WATER TEST REPORT

Pennsylvania has dozens of water-testing laboratories, each with its own way of presenting results. Your water test may not look exactly like the one shown in Figure 4.1 (on the following page), but it probably contains the same basic components. Read about each water test component below and try to find it on your own water test report. The numbered sections below correspond to the circled numbers shown in Figure 4.1.

Remember that these are only the most common components of a typical water test report. Some laboratories include additional information such as the method used for each test (usually an EPA number), the initials of the person who completed each test, and the date each test was completed. This information is generally unimportant to the client unless litigation is planned.

1. Client and Sample Information

Basic information at the top of most water test reports identifies the person who submitted the water sample, where the sample came from, who received it at the laboratory, etc. This is called the chain-of-custody information and could be very important if the results were to be used in any type of legal action.

2. Analysis

All water test reports list the water-quality parameters that were tested. The list includes only those you asked the laboratory to analyze or those the lab rec-

Figure 4.1. A typical water test report. *Supplied by the Penn State Agricultural Analytical Laboratory.*

PENNSTATE

Agricultural Analytical Services Laboratory
College of Agricultural Sciences
The Pennsylvania State University
University Park, PA 16802

Phone: 814-863-0841
Fax: 814-863-4540
Web: www.aasl.psu.edu

Analysis Report For:	Copy To:
Henry Homeowner 123 Farmland Road Waterville PA 11111 **1**	

LAB ID:	SAMPLE ID:	REPORT DATE:	DATE SAMPLED	SAMPLE TYPE:	COUNTY
W00001	Kitchen	3/31/2009	03/18/09	Drinking Water	Centre

WATER ANALYSIS
Agriculture/Septic Report Package (WD04)

Analysis **2**	Units **4**	Your Test Results **3**	Drinking Water Standard[1] Standard	Type **5**	Method
Total Coliform Bacteria	MPN[2] per 100 mL	78	0	Health	SM 9223B
E. Coli Bacteria	MPN[2] per 100 mL	None detected[3]	0	Health	SM 9223B
pH	-	6.1	6.5 - 8.5	Aesthetics	EPA 150.1
Total Dissolved Solids (TDS)	mg/L	396	500.0	Aesthetics	SM 2540C
Nitrate+Nitrite as N	mg/L	2.1	10	Health	EPA 353.2

Water sample failed the drinking water standard for TOTAL COLIFORM BACTERIA. **6**
Water sample failed the drinking water standard for pH.

For more details on your water test results, please see the description of each parameter on the back of this report and any fact sheets that may have been included with your results.

[1] US EPA has established public drinking water standards based on potential health effects (primary standard) or aesthetic effects such as taste, odor and color (secondary standard). For more detail, see description for each analysis on back of report.

[2] Probable number of colonies per 100 mL of water

[3] Detection limit: 1 MPN per 100 mL

ommended for your water sample. The number of parameters can vary from just a few to dozens of tests. Consult other sections of this chapter for a description of each of these tests.

3. Results

The most important pieces of information on your water test report are the actual results the laboratory found for your water sample. The numbers indicate the concentration of each water-quality parameter in your water sample. In some cases, the unit of measure for each test is shown next to the result. In others, the units are shown in a separate column (as in the sample test report in Figure 4.1). The result for each test should be compared to the drinking water standard for that parameter.

Sometimes, a water test result is reported as "ND" (not detected), which means that the lab was unable to detect any of that pollutant with its equipment. Similarly, some results may have a "less-than sign" (<) in front of a number. This result means the sample contained less than the detection level for that test. Detection levels are often set at the permissible drinking water concentration for a particular pollutant. If the less-than symbol (<) appears before a number and the number is equal to the drinking water standard, the water is likely safe to drink for that particular contaminant.

4. Units

Concentrations of pollutants are usually measured in water by a unit of concentration such as milligrams per liter (mg/L), or by a number such as number of bacteria per 100 milliliters of water (#/100 ml). You might see several different measurement units on your water test report. Refer to "Understanding Units" in the next section to learn more about these.

5. Standards

Many laboratories include the specific drinking water standards on the report next to each test result. This allows for an easy comparison of your result with the safe or recommended level for each test parameter. A complete list of drinking water standards can be found in Table 4.2.

6. Comments

Some water-testing laboratories include a brief explanation of your water test results. Specifically, they often list those pollutants that did not meet the drinking water standard. Occasionally, these comments also describe the potential harmful effects of pollutants that exceeded the standard and how these pollutants may be removed from the water.

Table 4.2. Drinking water standards as of April 2000.

Parameter	Standard	Unit
Microbial (all are primary standards)		
Total coliform bacteria	0	bacteria per 100 ml
Fecal coliform bacteria	0	bacteria per 100 ml
E. coli	0	bacteria per 100 ml
Giardia lamblia	0	oocysts
Cryptosporidium parvum	0	oocysts
Inorganic chemicals with primary standards		
Antimony (Sb)	0.006	mg/L
Arsenic (As)	0.010	mg/L
Asbestos	7 million	fibers/L
Barium (Ba)	2	mg/L
Beryllium (Be)	0.004	mg/L
Bromate	0.01	mg/L
Cadmium (Cd)	0.005	mg/L
Chlorite	1.0	mg/L
Chromium (Cr)	0.1	mg/L
Copper (Cu)	1.3	mg/L
Cyanide	0.2	mg/L
Fluoride (Fl)	4	mg/L
Lead (Pb)	0.015	mg/L
Mercury (Hg)	0.002	mg/L
Nitrate (as nitrogen) (NO_3-N)	10	mg/L
Nitrite (as nitrogen) (NO_2-N)	1	mg/L
Nitrate + nitrite (as nitrogen)	10	mg/L
Selenium (Se)	0.05	mg/L
Sulfate (SO_4) (proposed)	500	mg/L
Thallium (Tl)	0.002	mg/L
Volatile organic chemicals (all are primary standards)		
Benzene	0.005	mg/L
Carbon tetrachloride	0.005	mg/L
Chlorobenzene	0.1	mg/L
o-Dichlorobenzene	0.6	mg/L
p-Dichlorobenzene	0.075	mg/L
1,2-Dichloroethane	0.005	mg/L
1,1-Dichloroethylene	0.007	mg/L
cis-1,2-Dichloroethylene	0.07	mg/L
trans-1,2-Dichloroethylene	0.1	mg/L
Dichloromethane	0.005	mg/L
1,2-Dichloropropane	0.005	mg/L
Ethylbenzene	0.7	mg/L
Monochlorobenzene	0.1	mg/L
Styrene	0.1	mg/L
Tetrachloroethylene (PCE)	0.005	mg/L
Toluene	1	mg/L
1,2,4-Trichlorobenzene	0.07	mg/L
1,1,1-Trichloroethane	0.2	mg/L
1,1,2-Trichloroethane	0.005	mg/L
Trichloroethylene (TCE)	0.005	mg/L
Total trihalomethanes	0.08	mg/L
Vinyl chloride	0.002	mg/L
Xylenes (total)	10	mg/L

(Continued)

Table 4.2. Drinking water standards as of April 2000 (continued).

Parameter	Standard	Unit
Microbial (all are primary standards)		
Synthetic organic chemicals (all are primary standards)		
Alachlor	0.002	mg/L
Atrazine	0.003	mg/L
Benzo(a)pyrene	0.0002	mg/L
Carbofuran	0.04	mg/L
Chlordane	0.002	mg/L
2,4-D	0.07	mg/L
Dalapon	0.2	mg/L
Dibromochloropropane (DBCP)	0.0002	mg/L
Di(2-Ethylhexyl) adipate	0.4	mg/L
Di(2-Ethylhexyl) phthalate	0.006	mg/L
Dinoseb	0.007	mg/L
Diquat	0.02	mg/L
Endothall	0.1	mg/L
Endrin	0.002	mg/L
Ethylene dibromide (EDB)	0.00005	mg/L
Glyphosate	0.7	mg/L
Heptachlor	0.0004	mg/L
Heptachlor epoxide	0.0002	mg/L
Hexachlorobenzene	0.001	mg/L
Hexachlorocyclopentadiene	0.05	mg/L
Lindane	0.0002	mg/L
Methoxychlor	0.04	mg/L
Oxamyl (Vydate)	0.2	mg/L
PCBs	0.0005	mg/L
Pentachlorophenol	0.001	mg/L
Picloram	0.5	mg/L
Simazine	0.004	mg/L
2,3,7,8-TCDD (Dioxin)	0.00003	μg/L
Toxaphene	0.003	mg/L
2,4,5-TP (Silvex)	0.05	mg/L
Radionuclides (all are primary standards)		
Alpha emitters	15	pCi/L
Radium 226 + 228	5	pCi/L
Radium 226	20	pCi/L
Radium 228	20	pCi/L
Beta-particle and photon emitters	4	mrem
Radon (proposed)	300	pCi/L
Uranium	30	μg/L
Inorganic chemicals with secondary drinking water standards		
Aluminum (Al)	0.05-0.2	mg/L
Chloride (Cl)	250	mg/L
Color	15	color units
Copper (Cu)	1.0	mg/L
Corrosivity	Noncorrosive	
Fluoride	2	mg/L
Foaming agents	0.5	mg/L
Iron (Fe)	0.3	mg/L
Manganese (Mn)	0.05	mg/L
Odor	3	T.O.N.
pH	6.5-8.5	pH units
Silver (Ag)	0.1	mg/L
Sulfate (SO_4)	250	mg/L
Total dissolved solids (TDS)	500	mg/L
Zinc (Zn)	5	mg/L

Note: Standards in mg/L can be converted to μg/L units by multiplying by 1,000.

WHAT ARE DRINKING WATER STANDARDS?

Drinking water standards give the level of a pollutant that is acceptable in water. These standards are set by the U.S. Environmental Protection Agency (EPA) using available research data. The EPA sets standards for contaminants that are known to occur in water, are detectable in water, and cause a health or aesthetic problem in water. While EPA sets these standards, it is up to the Pennsylvania Department of Environmental Protection to enforce the standards when and where they apply.

Two types of drinking water standards are used: primary and secondary. Primary standards are set for contaminants that cause some health effect such as illness, disease, cancer, or another health problem. Adherence to these standards is mandatory for public water systems, but for private water systems these standards are voluntary. Primary standards are also known as Maximum Contaminant Levels, or MCLs.

Secondary standards are created for water contaminants that cause aesthetic problems such as bad taste, discoloration, or odor. In the past, these standards were always voluntary and were used mainly as guides. Recently, however, some community water systems have been required to meet some of them. Secondary standards are also known as Secondary Maximum Contaminant Levels (SMCLs) or Recommended Maximum Contaminant Levels (RMCLs).

Understanding Units

All drinking water test results and standards have a unit associated with them. These units give the amount of the pollutant per some quantity of water. The most common unit is the milligram per liter (mg/L), which expresses the milligrams of a pollutant in every liter of water. Some laboratories prefer to use parts per million (ppm), which is identical to milligrams per liter. Some contaminants that can be measured in very low quantities are reported in micrograms per liter (μg/L), which is identical to a part per billion (ppb). Keep in mind that concentrations expressed in mg/L (or ppm) can be converted to μg/L (or ppb) by multiplying by 1,000, and that μg/L (or ppb) can be converted to mg/L (or ppm) by dividing by 1,000.

Most pollutants occur in water in very low concentrations. The following examples illustrate just how small these units really are.

- One milligram per liter (mg/L) or part per million (ppm) corresponds to one minute in two years or a single penny in $10,000.
- One microgram per liter (μg/L) or part per billion (ppb) corresponds to one minute in 2,000 years or a single penny in $10,000,000.

Although most water-quality measurements are expressed in these units, some tests such as those for bacteria, corrosivity, turbidity, and radon use different units. To learn more about these other units, refer to the discussions on individual parameters in the following section.

DESCRIPTION OF COMMON POLLUTANTS (by Category)

Hundreds of pollutants can occur in drinking water in Pennsylvania. They can be grouped into four basic categories: microbial, inorganic, organic, and radiological. Although over 100 pollutants have drinking water standards (see Table 4.2 for a complete list), many of these pollutants are uncommon in Pennsylvania. The following sections discuss forty of the most common pollutants in Pennsylvania drinking water. These pollutants are listed alphabetically within the four categories.

Microbial Pollutants

Microbial pollutants include bacteria, viruses, and protozoans. These are living organisms that are visible in water only with the help of a high-powered microscope. Many different kinds of bacteria, some disease-causing but many not, may be present in a water supply. The tests discussed below are specific bacteria tests that are used to determine whether disease-causing bacteria are present in the water. Protozoans are less common in water than bacteria, but a few can pose problems. Viruses are not discussed here because they rarely occur in Pennsylvania drinking water; however, viruses such as hepatitis are carried by water and can cause serious illness.

Coliform Bacteria

Coliform are a large group of bacteria that occur throughout the environment. They are used as an indicator organism to show the potential for disease-causing bacteria to be present in water. In other words, if coliform bacteria are present, it is presumed that a contamination pathway exists between the bacteria source and the water supply, and disease-causing bacteria may use this pathway to enter the water supply. Coliform bacteria occur frequently in private water systems, usually from contamination by surface runoff or from human or animal wastes.

Most coliform bacteria do not cause disease, but the greater their number the greater the likelihood that disease-causing bacteria may be present. Since coliforms persist in water longer than most disease-causing organisms, the absence of coliform bacteria leads to the assumption that the water supply is microbiologically safe to drink. Consuming water with coliform bacteria present may cause gastrointestinal illnesses, fever, and other flulike symptoms. Therefore, the drinking water standard requires that no coliform bacteria be present in public drinking water supplies.

Results from coliform bacteria tests are normally expressed as the number of bacteria colonies present per 100 milliliters (ml) of water. Some laboratories may simply express coliform bacteria results as "present" (P) or "absent" (A). In this case, "present" indicates only that at least one bacterium was present in each 100 ml of water. Occasionally, bacterial results are expressed as "MPN," which stands for Most Probable Number. This simply means that a statistical relationship was used to estimate the number of bacteria in your sample. Finally, bacteria results also may be reported as "TNTC," or "too numerous to count," meaning the bacterial concentration was too high to quantify.

Fecal Coliform Bacteria

Fecal coliform bacteria are a smaller group within the coliform bacteria group. Water may be tested for fecal coliform bacteria if the total coliform test is positive. Fecal coliform bacteria are specific to the intestinal tracts of warm-blooded animals and are thus a more specific test for sewage or animal waste contamination. The ratio of fecal coliform bacteria to fecal streptococcus bacteria has been used to estimate the source of bacterial contamination (see discussion below). Fecal coliform bacteria levels are expressed as the number of colonies per 100 ml of water. No fecal coliform bacteria are permitted in public drinking water supplies.

Fecal Streptococcus Bacteria

Fecal streptococcus bacteria are another smaller group within the coliform bacteria group and are especially numerous in animal waste (as opposed to human waste). The ratio of fecal coliform to fecal streptococcus bacteria is usually much higher in humans than it is in animals. As a rule of thumb, a fecal coliform to fecal streptococcus ratio greater than 4.0 is indicative of a human source of bacteria such as a septic system. A ratio less than 1.0 is indicative of an animal source of bacteria such as runoff from a feedlot. Ratios between 1.0 and 4.0 are inconclusive about the source of the bacteria. Fecal streptococcus bacteria are expressed as the number of colonies per 100 ml of water. No fecal streptococcus bacteria are permitted in drinking water.

E. Coli

An even more specific bacterial test is conducted for *E. coli* (short for *Escherichia coli*). This is a type of fecal coliform bacteria commonly found in the intestines of animals and humans. A positive *E. coli* result is a strong indication that human sewage or animal waste has contaminated the water.

Hundreds of strains of *E. coli* exist. Although most are harmless and live in the intestines of healthy humans and animals, a few can produce a powerful toxin that causes severe illness and even death. Infection often causes severe bloody diarrhea and abdominal cramps; sometimes the infection causes nonbloody diarrhea. Frequently, no fever is present. It should be noted that these symptoms are common to a variety of diseases and may be caused by sources other than contaminated drinking water.

E. coli tests are reported as the number of bacteria per 100 ml of water. The presence of any *E. coli* in a water sample is unacceptable; thus, the primary drinking water standard for *E. coli* is 0 per 100 ml of water.

Standard Plate Count (Heterotrophic Plate Count)

The Standard Plate Count (SPC) or Heterotrophic Plate Count (HPC) is a more general indicator of bacterial contamination. On some test reports, this also may be referred to as the "Total Bacteria Count." It measures all of the bacteria, including coliform and many other groups, in a water sample. The SPC is usually reported as the number of bacteria per mL of sample. This test has become rare over time due to uncertainty in the interpretation of the results. As a result, there are no drinking water standards for SPC, but if more than 500 bacteria are counted in one mL of sample, further testing for total coliform or fecal coliform bacteria is suggested.

Iron Bacteria

Iron bacteria feed on small amounts of iron in water. While they do not constitute a health threat, they are a nuisance in private water systems because they form gelatinous strands, masses, or thin films that plug pipes, toilets, and plumbing fixtures and reduce flow from wells. Their appearance can vary from orange or brown to clear. Iron bacteria can colonize an entire water system from the well itself through the plumbing, or they may be present only in parts of the plumbing system.

There are no drinking water standards for iron bacteria. Rather, their presence is normally aesthetically degrading enough to require treatment. Water testing is rarely available to determine if iron bacteria are present. Confirmation is usually based on the visual symptoms in the water, or on microscopic analysis by someone familiar with these bacteria.

Giardia *and* Cryptosporidium

Giardia lamblia and *Cryptosporidium parvum* are small microscopic animals known as protozoa. They both can live in the intestinal tracts of mammals, including humans. While there, they multiply by producing oocysts. Infected animals and humans can excrete the oocysts, which can then contaminate water sources. Once ingested, the organism emerges from the protective oocyst and infects the lining of the intestine. Both giardiasis and cryptosporidiosis cause severe diarrhea, nausea, fever, headache, vomiting, and loss of appetite. Both illnesses can be life-threatening for people with depressed immune systems.

Many private water system owners are familiar with *Giardia* and *Cryptosporidium* as a result of publicity following outbreaks of illnesses in public water supplies. Most of these outbreaks have occurred in communities that use surface water supplies (streams, rivers, lakes) where the oocysts can commonly be found. *Giardia* and *Cryptosporidium* are rarely a concern for private water systems using deeper groundwater sources, because the oocysts are efficiently filtered as water passes through soil and rock. Shallow springs or poorly constructed wells that become contaminated with surface water are the most likely to contain *Giardia* and *Cryptosporidium* oocysts. This is one reason that roadside springs are not a good alternative source of drinking water.

Both *Giardia* and *Cryptosporidium* are measured by filtering large volumes of water through a small filter and examining the filter under a microscope for oocysts. Oocysts should be totally absent from water for it to be safe to drink.

Inorganic Chemicals (IOCs)

The second category of water pollutants includes inorganic chemicals. These are usually substances of mineral origin. Salt, metals, and minerals are examples. The chemicals listed alphabetically below are the most common inorganic pollutants in Pennsylvania water supplies, or they are of the greatest health concern. Unless otherwise stated, these inorganic chemicals are usually reported in mg/L or ppm units.

Alkalinity

Alkalinity is a commonly measured water characteristic that has little meaning or importance for the typical homeowner. It is a measure of water's ability to neutralize acids. Calcium is a major component of alkalinity and of hard water. Thus, if your water has a high alkalinity, it is probably hard as well. There is no drinking water standard for alkalinity.

Arsenic (As)

Arsenic occurs in groundwater from both natural sources and human activities. In drinking water, it is odorless and tasteless. It is relatively rare in Pennsylvania water supplies, compared to those of the western United States.

In Pennsylvania, arsenic can originate naturally from certain types of rock, or it may be traced to deepwater brines produced from gas and oil well drilling or from industrial activity. Arsenic has a primary drinking water standard because it can cause skin lesions, circulatory problems, and nervous system disorders. Prolonged exposure also can cause various forms of cancer. The present arsenic drinking water standard is 10 µg/L (0.010 mg/L). A survey conducted by Penn State in 2006-07 found that arsenic exceeded 10 µg/L in 2 percent of wells in Pennsylvania. Wells with high arsenic levels are more common north of Interstate 80 owing to the natural geology of these areas.

Barium (Ba)

Like arsenic, barium occurs naturally in small concentrations in many groundwater supplies. Barium contamination is not common in private water systems in Pennsylvania, but it may occur sporadically in western and northern Pennsylvania near active and abandoned gas and oil wells.

Barium has a primary drinking water standard of 2.0 mg/L because it causes nervous and circulatory system problems, especially high blood pressure. Standard water softeners are effective in removing barium.

A study of barium levels in McKean County (a county with intensive gas well drilling) found excessive barium in about 2 percent of private wells in the county.

Chloride (Cl)

Chloride is common in Pennsylvania water supplies, but it rarely reaches levels of concern. It occurs naturally in most groundwater but may become elevated due to leaching from salt storage areas around highways or from brines produced during gas well drilling. Other possible sources of chloride are sewage effluent, animal manure, and industrial waste.

Chloride has a secondary drinking water standard of 250 mg/L because it may cause a salty taste in the water. Groundwater in Pennsylvania usually contains less than 25 mg/L of chloride.

Copper (Cu)

Copper usually originates from corrosion of copper plumbing in the home (see “Corrosivity,” below). Copper has a secondary drinking water standard of 1.0 mg/L because it causes a bitter, metallic taste in water and a blue-green stain in sinks and bathtubs. It has a primary standard of 1.3 mg because of health concerns related to severe stomach cramps and intestinal illnesses. Copper can be reduced in water using the corrosion control strategies outlined below.

Corrosivity

Corrosive water is a term used to describe aggressive water that can dissolve materials with which it comes in contact. It is a problem because many homes have copper or galvanized pipes, lead solder joints, and brass plumbing fixtures. Thus, corrosive water may cause increases in copper and lead concentrations in drinking water. In rare cases, corrosive water may dissolve even PVC plastic plumbing, causing vinyl chloride contamination of the water. This generally occurs only when inferior plastic pipe that was not approved for drinking water systems has been used. Approved plastic pipe is directly stamped with “NSF” (National Sanitation Foundation) and “Drinking Water” on the side.

Symptoms of corrosive water problems include metallic taste, bluish green stains in sinks and bathtubs, and, in severe cases, small leaks in the plumbing system. Because corrosive water is not a health concern by itself, there is only a secondary or recommended standard that water be noncorrosive.

Water that is soft and acidic (pH < 7.0) tends to be more corrosive, but the only true measure of water corrosivity is a stability or saturation index. These indices use the water’s chemical characteristics such as hardness and pH to estimate its corrosiveness. A stability index greater than about 6.5 indicates water that is probably corrosive, with higher values being increasingly corrosive. A negative saturation index value likewise indicates a corrosive water supply. The most common saturation index in use is the Langelier Saturation Index (LSI).

Past surveys of private water supplies in Pennsylvania have indicated that corrosive water is a common water-quality problem, present in over 60 percent of the groundwater wells and springs tested. It tends to be most common in northern and western Pennsylvania where more acidic groundwater is prevalent, although areas underlain by Triassic shales in southeastern Pennsylvania also produce corrosive water. It is least common in the agricultural valleys underlain by limestone where groundwater typically has a higher pH and hardness. Cistern water can be quite corrosive.

If your water test indicates that your water is corrosive, you should test your water for copper and lead. Corrosive water problems can be corrected using an acid-neutralizing filter or by replacing metal plumbing with plastic components approved by the National Sanitation Foundation (NSF).

Hardness

Hardness is a general term used to refer to the water’s calcium carbonate ($CaCO_3$) content. Hardness does not pose a health threat, but it does cause aesthetic problems. It can ruin hot water heater elements, reduce soap lathering, and make laundry difficult to clean. Moderate levels of hardness are beneficial because they inhibit plumbing system corrosion. Removal of hardness using a water softener is necessary only if the water is causing aesthetic problems. Use of water softeners may result in undesirable levels of sodium in drinking water and may increase plumbing system corrosion.

Hardness may be reported in milligrams per liter (mg/L) or in a special unit called grains per gallon (gpg). One grain per gallon is equal to about 17 mg/L or parts per million (ppm). Since the level of hardness or calcium carbonate means little to consumers, a water hardness classification has been developed and appears in Table 4.3. A water hardness of about 90 to 100 mg/L provides excellent corrosion control and is usually acceptable aesthetically, but there are no drinking water standards for hardness.

Hydrogen Sulfide (H_2S)

Hydrogen sulfide (H_2S) is a noxious gas that imparts a disagreeable rotten egg odor when dissolved in water. It is a naturally occurring gas that is common in groundwater in parts of Pennsylvania. Very small concentrations of hydrogen sulfide in water are offensive to most individuals. Although hydrogen sulfide is a highly toxic gas, only under the most unusual conditions would it reach levels toxic to humans as a result of its presence in drinking water. More often, it is simply an unpleasant odor problem that can be removed using several treatment processes.

Iron (Fe)

Iron is a common natural problem in groundwater in Pennsylvania and may be worsened by mining activities. It occurs throughout Pennsylvania but is most problematic in the western region. Iron does not occur in drinking water in concentrations of health concern to humans. The secondary drinking water standard for iron is 0.3 mg/L because it causes a metallic taste and orange-brown stains that make water unsuitable for drinking and clothes washing.

Lead (Pb)

If lead is detected in your drinking water, it probably originated from corrosion of your plumbing system. Lead was a common component of solders used in plumbing systems until it was banned in 1991. In homes built in the early 1900s, lead pipe also may be present. Thus, if your home was built before 1991 and has a metal plumbing system, it is likely that some lead is present. If your water supply is corrosive (see discussion above), then any lead present in the plumbing system may be dissolved into your drinking water. Lead concentrations are usually highest in the first water out of the tap (known as "first-draw" water), since this water has been in contact with the plumbing for a longer time. Lead concentrations typically decrease as water is flushed through the plumbing system.

A survey in 1989 found that about 20 percent of the private water supplies in Pennsylvania contained lead concentrations above the MCL of 0.015 mg/L (15 µg/L). In 1991 the federal government took steps to limit lead in water plumbing systems. As a result, a recent survey of private water systems in Pennsylvania found that lead contamination had declined from 20 percent in 1989 to 12 percent in 2007 (Swistock et al. 2009).

Lead levels can seriously threaten drinking water safety. Lead is colorless, odorless, and tasteless. Long-term exposure to lead concentrations in excess of the drinking water standard has been linked to many health effects in adults, including cancer, stroke, and high blood pressure. At even greater risk are the fetus and infants up to four years of age, whose rapidly growing bodies absorb lead more quickly and efficiently. Lead can cause premature birth, reduced birth weight, seizures, behavioral disorders, brain damage, and lowered IQ in children. The U.S. Environmental Protection Agency considers lead to be the most serious environmental health hazard for children in the United States.

More than 90 percent of lead problems in drinking water can be traced to corrosive water and lead impurities in the plumbing system. It should be noted, however, that in rare cases the source of lead in drinking water might be groundwater pollution rather than corrosion of the plumbing system. Such pollution may be the result of industrial or landfill contamination of an aquifer. The source of the lead usually can be determined by comparing water test results from a first-draw sample versus a sample collected after the water runs for several minutes. If the lead concentration is high in both samples, then the source of the lead is likely from groundwater contamination.

Manganese (Mn)

Like iron, manganese is a naturally occurring metal that may be worsened by mining activities. Manganese concentrations normally found in drinking water do not constitute a health hazard; however, even small amounts of manganese may impart objectionable tastes or blackish stains to water. For this reason, manganese has a recommended drinking water standard of 0.05 mg/L.

Table 4.3. Water hardness classifications.

Classification	Hardness (mg/L or ppm)	Hardness (gpg)
Soft	Less than 17	Less than 1.0
Slightly hard	17 to 60	1.0 to 3.5
Moderately hard	60 to 120	3.5 to 7.0
Hard	120 to 180	7.0 to 10.5
Very hard	More than 180	More than 10.5

Nitrate (NO_3) or Nitrate Nitrogen (NO_3-N)

Nitrate in drinking water usually originates from fertilizers or from animal or human wastes. Nitrate concentrations in water tend to be highest in areas of intensive agriculture or where there is a high density of septic systems. In Pennsylvania, nitrate exceeds 10 mg/L in about 2 percent of all private water systems, but in the southeastern and southcentral counties where agriculture is most prevalent, it exceeds 5 percent.

Nitrate has a primary drinking water standard that was established to protect the most sensitive individuals in the population (infants under 6 months of age and a small component of the adult population with abnormal stomach enzymes). These segments of the population are prone to methemoglobinemia (blue baby disease) when consuming water with high nitrates. The need for a nitrate MCL has been questioned lately because blue-baby disease occurs very rarely in the United States.

Nitrate may be reported on your water test report as either nitrate (NO_3) or nitrate-nitrogen (NO_3-N). Look carefully at your report to determine which form of nitrate is being reported. The primary drinking water standard or MCL is 10 mg/L as nitrate-nitrogen (NO_3-N), but it is 45 mg/L as nitrate (NO_3).

pH

The pH of water is a measure of how acidic or basic the water is. It is measured on the pH scale (from 0 to 14) in pH units. If the pH of water is less than 7.0, it is acidic, and if it is greater than 7.0, it is basic. Water with a pH of exactly 7.0 is considered neutral. If pH values deviate very far from neutral, other water-quality problems may be indicated. These would include the presence of toxic metals such as lead (at low pH) and high salt contents (at high pH).

It is recommended that the pH of your water be between 6.5 and 8.5 to minimize other potential water-quality problems. Acidic water with a pH less than 6.5 is much more common in Pennsylvania (occurring in 18 percent of private wells) than high-pH water (occurring in only 2 percent of private wells), especially in the northern and western regions of the state. In general, pH is an indicator of other potential water-quality problems and is very rarely a problem by itself.

Sulfate (SO_4)

Sulfates normally are present at some level in all private water systems. Sulfates occur naturally as a result of leaching from sulfur deposits in the earth, or from the breakdown of sulfate minerals in the environment, such as the weathering of iron pyrite ($FeSO_4$). Private water systems with excessive sulfate in Pennsylvania are generally confined to the western portions or other coal-mining regions. Even in these areas, surveys indicate that less than 10 percent of the water supplies have excessive sulfate. Other less common sources are industrial waste, sewage effluent, and gas wells.

Sulfate has a secondary drinking water standard of 250 mg/L because it may impart a bitter taste to the water at this level. A proposal also exists to make sulfate a primary contaminant with an MCL of 500 mg/L, because it may have a laxative effect and cause other gastrointestinal upsets above this concentration.

Total Dissolved Solids (TDS)

The total amount of substances dissolved in water is referred to as the total dissolved solids (TDS) content of water. Waters high in TDS often contain objectionable levels of dissolved salts such as sodium chloride. Thus, high TDS may indicate the presence of other water-quality problems. The recommended drinking water standard of 500 mg/L for TDS exists because high-quality waters generally have lower TDS levels.

Turbidity

Drinking water should be sparkling clear for health and aesthetic reasons. Turbidity refers to fine particles of clay, silt, sand, organic matter, or other material that might reduce the clarity of water. Turbidity makes water unappealing to drink because of its muddy appearance. Particles also might act to shield disease-causing bacteria from chlorine or ultraviolet light treatment and provide nutrients for bacteria and viruses to flourish.

Turbidity usually indicates direct pollution from surface runoff often during or shortly after heavy rainfall. Turbidity might increase in wells because of borehole cave-ins; it also might increase when water levels in the well are low such as during a drought, because the submersible pump may disturb sediments near the bottom of the well.

Turbidity is usually measured in a special unit known as an NTU, or Nephelometric Turbidity Unit. Drinking water should not exceed 1 NTU, for both health and aesthetic reasons. Water with even 10 NTUs of turbidity is essentially clear to the naked eye; thus, testing is required. Water with more than 1 NTU of turbidity makes disinfection to kill bacteria difficult and is the primary reason for the 1 NTU standard.

Organic Chemicals

Organic chemicals are a large group of over 100 mostly human-made chemicals. They can occur in drinking water sources from industrial activity, landfills, gas stations, pesticide use, or air deposition. Organic chemicals vary in their ability to pollute groundwater and their toxicity. Many organic chemicals are carcinogenic (cancer causing), so they often have very low drinking water standards, usually measured in µg/L. Remember that µg/L are the same as ppb (parts per billion).

Generally speaking, organic chemicals can be grouped into two major categories: volatile organic chemicals (VOCs) and nonvolatile or synthetic organic chemicals (SOCs). The discussion below introduces these general groups of organic chemicals and describes in detail the most common examples in each group. Specific drinking water standards for all organic chemicals are given in Table 4.2.

Volatile Organic Chemicals (VOCs)

VOCs are human-made compounds that volatilize from water into air. They present a health risk not only from drinking contaminated water, but also from inhaling VOCs that escape from the water as it is used during showering or other home uses. VOCs also are absorbed directly through the skin during bathing and showering. They are commonly used as solvents, fuels, paints, or degreasers. Virtually all VOCs produce an odor in water, although it may not be obvious before the drinking water standard is exceeded. Nearly all VOCs have primary drinking water standards, because they are carcinogenic (cancer-causing) or cause damage to the liver, kidneys, nervous system, or circulatory system.

VOCs are not common in private water systems in Pennsylvania, but they are becoming a more important concern as industrial activities, landfills, gas stations, and other sources of these pollutants encroach on rural areas. The U.S. Geological Survey conducted a survey of 118 wells in southern and eastern Pennsylvania. The survey analyzed well water for 60 different VOCs and detected at least one VOC in 27 percent of the samples. (Although the VOCs were commonly detected, none of the samples exceeded drinking water standards.) VOC contamination of wells was much more common in urban areas than agricultural areas (Zogorski et al. 2006).

Dozens of VOCs are regulated in public water supplies, but the most common are described below. Consult Table 4.2 for a complete list of drinking water standards for all regulated VOCs.

Benzene

Benzene is a clear liquid that is used primarily as an industrial solvent and chemical intermediate. It is lighter than water, migrates easily in groundwater, and is slow to decay. It is also present as a gasoline additive. Because it is a known human carcinogen, benzene has a primary drinking water standard of 0.005 mg/L (5 µg/L).

Carbon Tetrachloride

Carbon tetrachloride is a colorless liquid that is heavier than water but migrates easily in groundwater. It has been used mostly for the production of chlorofluorocarbons and in the dry-cleaning industry. Carbon tetrachloride has a primary drinking water standard of 0.005 mg/L (5 µg/L) because it is a probable human carcinogen with other acute effects on the gastrointestinal and nervous systems.

Chloroform

Chloroform is a colorless liquid that is used primarily to make other chemicals. It also can be found in small amounts when chlorine is added to water. Chloroform travels easily in groundwater and does not easily degrade. Chloroform is believed to be a carcinogen. It has been one of the most commonly reported organic chemicals in Pennsylvania groundwater.

Chloroform is one of a group of organics known as trihalomethanes or THMs. No specific drinking water standard exists for chloroform, but the primary standard for THMs is 0.08 mg/L (80 µg/L).

MTBE (Methyl Tert-Butyl Ether)

MTBE is the most common organic chemical found in Pennsylvania groundwater. It has been used extensively as a gasoline additive in some parts of the United States to reduce air pollution emissions from automobiles. It smells like turpentine and can often be detected in water at low concentrations. Most MTBE originates from gasoline spills or leaking underground storage tanks. It is more water soluble than other components of gasoline, so it contaminates groundwater more easily. Once in groundwater, MTBE is slow to decay. MTBE is a possible human carcinogen, but little information is available on other health effects. Pennsylvania presently has no drinking water standard, but numerous other states have set standards in the 0.02 to 0.2 mg/L range (20 to 200 µg/L). More information on MTBE is available online at www.epa.gov/safewater/contaminants/unregulated mtbe.html. Other online resources for MTBE can be found at www.epa.gov/swerust1/mtbe/othrlink.htm#/.

Tetrachloroethylene (PCE) and Trichloroethylene (TCE)

Tetrachloroethylene (commonly known as PCE) and trichloroethylene (commonly known as TCE) are similar chemicals that have been found in Pennsylvania around industrial sites and landfills. Most of the groundwater contamination from these chemicals has occurred because of improper disposal of industrial wastes. Both chemicals are used as industrial solvents for metal degreasing, but PCE is used primarily in the dry-cleaning industry. Both are heavier than water and move freely through soil and groundwater, but TCE is much more water soluble than PCE. PCE is a possible carcinogen that causes liver, kidney, and nervous system damage. TCE is a probable carcinogen that also causes acute effects to the liver, kidneys, and central nervous system. Both PCE and TCE have primary drinking water standards of 0.005 mg/L (5 µg/L).

Xylenes

Xylenes are a component of gasoline. They also are used in the manufacturing of some chemicals and therefore appear commonly in industrial wastes. Xylenes cause liver, kidney, and nervous system damage. Xylenes biodegrade and move slowly in groundwater. Xylene has been reported in much higher concentrations than most other VOCs in Pennsylvania, but the drinking water standard for xylenes is also much higher (10 mg/L or 10,000 µg/L).

Nonvolatile or Synthetic Organic Chemicals (SOCs)

Nonvolatile organic chemicals are also known as synthetic organic chemicals, or SOCs. Nearly all SOCs are pesticides, with a few notable exceptions (PCBs and dioxin). They differ from VOCs because they do not escape readily into the air from water.

Dozens of pesticides, including herbicides, insecticides, and fungicides, are used throughout Pennsylvania on crops, golf courses, and lawns. The risk to private water supplies from pesticide applications depends on many factors, including the amount, mobility, and toxicity of the pesticide, the proximity of the application to the water supply, and the depth and construction of the water source.

Pesticides are not common in private water supplies, but they are often detected in agricultural areas of the state. An unpublished 1993 study by Penn State scientists found detectable residues of at least one pesticide in 27 percent of the rural wells surveyed in corn-producing regions of Pennsylvania. (Although the pesticides were commonly detected, none of these wells contained a concentration above the drinking water standard.) A more recent 2006-07 Penn State study found unsafe levels of triazine pesticides (atrazine, simizine, etc.) in just 3 of 701 wells statewide (Swistock et al. 2009). Pesticide concentrations are generally higher in wells located in limestone, which includes most of the prime agricultural regions of Pennsylvania.

Detailed descriptions are given below for some of the pesticides most often found in Pennsylvania groundwater. For more information on these and other less common pesticides visit www.epa.gov/pesticides/ or www.cas.psu.edu/docs/casdept/pested/index.html. A publication (NRAES-34), *Pesticides and Groundwater*, can be ordered from NRAES, www.nraes.org.

Atrazine

Atrazine is the most commonly used herbicide in Pennsylvania. It is applied to nearly 90 percent of the state's corn crop. It is water soluble, moves easily into groundwater and surface water after application, and is by far the most common pesticide reported in private water supplies in Pennsylvania. Because it is classified as a possible human carcinogen that also damages the liver, kidney, and heart, atrazine has a primary drinking water standard of 0.003 mg/L (3 µg/L).

2,4-Dichlorophenoxyacetic Acid (2,4-D)

2,4-D is widely used to kill broad-leaved weeds in farm fields and pastures and on lawns and golf courses. It also is used to kill algae and aquatic plants in ponds and lakes. 2,4-D damages the liver, circulatory, and nervous systems. Like atrazine, it is one of the most commonly used pesticides in Pennsylvania and one of those most often found in groundwater in the state's agricultural areas. 2,4-D has a primary drinking water standard of 0.07 mg/L (70 µg/L).

Chlorpyrifos

Chlorpyrifos, also known as Dursban, has been one of the most commonly used insecticides on corn crops in Pennsylvania. It has also been used to control pests on cattle, and it was widely used around the home for control of cockroaches, fleas, and termites. Chlorpyrifos does not mix well with water and sticks tightly to soil particles. It was detected in trace amounts in a small percentage of private water systems in a 1993 study. Chlorpyrifos is presently considered a possible human carcinogen. No drinking water standard exists for chlorpyrifos, but the U.S. Environmental Protection Agency (EPA) recommends that children not drink water containing levels greater than 0.03 mg/L. The use of chlorpyrifos was severely restricted as of December 31, 2001 The EPA announced a ban on the production of chlorpyrifos, starting in June 2000.

Glyphosate

Glyphosate is one of the most widely used pesticides in the United States. It is a herbicide used mostly to control broad-leaved weeds and grasses in pastures, corn, soybeans, and lawns. It is a component of the often-used herbicide Roundup®. Glyphosate has a primary drinking water standard of 0.7 mg/L (700 µg/L) because it causes kidney damage and reproductive effects after long-term exposure. Glyphosate is strongly adsorbed to soil and does not readily move to or in groundwater.

Metolachlor

Metolachlor is the second most commonly used herbicide on corn in Pennsylvania. It is slightly less mobile than atrazine but still moves easily through soil to groundwater. A 1993 survey of private water systems in Pennsylvania found metolachlor to be the third most commonly detected pesticide in the state. There are no reported short-term effects from exposure to metolachlor in water, but it is listed as a possible carcinogen with prolonged exposure. No drinking water standard exists, but further testing is being done by the EPA. In the interim, the EPA has issued a health advisory for metolachlor of 0.07 mg/L (70 μg/L).

Simazine

Simazine is commonly used to control broad-leaved and grassy weeds on crops, orchards, and Christmas tree farms. It has a primary drinking water standard of 0.004 mg/L (4 μg/L) because it is a probable carcinogen that also can damage the testes, kidneys, liver, and thyroid after long exposure. Simazine travels easily through soils to groundwater and persists in groundwater for long periods of time.

Dioxin (2,3,7,8-TCDD)

Dioxin (also known as 2,3,7,8-Tetrachlorodibenzo-1-,4-dioxin or 2,3,7,8-TCDD) is a contaminant formed in the production of some chlorinated organic compounds, including a few herbicides. It may also be formed when some chlorinated organic chemicals are burned. Dioxin has been linked to a variety of health effects, including liver damage, reproductive effects, birth defects, and cancer. Most dioxin in water comes from improper disposal of industrial wastes. It is not very water soluble, and most dioxin is found adhering to sediment or organic particles. It does not move easily into groundwater because it is usually trapped in soil. It has the lowest drinking water standard of any regulated substance (0.00000003 mg/L or 0.00003 μg/L).

Polychlorinated Biphenyls (PCBs)

PCBs are a group of manufactured organic chemicals that are odorless and tasteless in water, and pervasive and persistant in the environment. They have been used widely as insulating materials, coolants, and lubricants in electrical equipment. The manufacture of PCBs stopped in the United States in 1977 because of health effects, but products containing PCBs are still prevalent. Most PCBs in groundwater originate from improper waste disposal. In water, a small amount of PCBs may remain dissolved, but a larger amount sticks to organic particles and sediments. PCBs have been shown to cause numerous health effects, including liver, kidney, and nervous system damage. They are also considered probable carcinogens. As a result, a primary drinking water standard of 0.0005 mg/L (0.5 μg/L) exists for PCBs.

Radiological Pollutants

Radioactivity usually occurs in water from radium, uranium, or radon. These materials emit radioactivity as alpha, beta, or gamma radiation. Each form of radiation affects the human body differently, yet all can lead to cancer. Radioactivity in water is normally measured in picocuries per liter (pCi/L). Several drinking water standards exist for radioactivity (see Table 4.2). Radon is likely to be the most common radiological problem in Pennsylvania.

Radon

Radon is a naturally occurring radioactive gas formed underground by the decay of uranium or radium deposits. Radon can enter groundwater as it escapes from surrounding rocks. The gas is then released during household uses of the water such as showering, dishwashing, or laundering. Radon has been shown to cause lung cancer upon inhalation, but ingestion of radon in water is not thought to be a major health concern. Thus, the most serious threat from radon in water is the inhalation of escaping gas during showering or bathing. For this reason, the U.S. EPA has proposed drinking water standards for radon in water ranging from 300 to 4,000 pCi/L.

Recent surveys by the Pennsylvania Department of Environmental Protection and the U.S. Geological Survey indicate that over 60 percent of the private water supplies in Pennsylvania contain more than 300 pCi/L of radon; about 20 percent exceed 4,000 pCi/L of radon. The problem is most severe in southeastern counties, but it is present throughout the state.

Chapter 5—Solving Water-Quality Problems

It is not uncommon for drinking water supplies to become contaminated by either natural or human-made processes. However, private water system owners are especially vulnerable to drinking water from unsafe sources, since testing is not required and most rural homeowners do not know what they should be testing their water for on a regular basis. Homeowners relying on private water supplies should take the time to learn what water tests are needed, how to take the sample, where to go to have the sample analyzed, and how to interpret the results. Testing should be done on a regular basis and reports kept in a secure location with other important documents (see Chapter 4 for details).

Once testing has been completed by a state-certified laboratory and the results accurately interpreted, you can make the necessary decisions regarding how to solve water-quality problems. Immediately identifying and contacting a water treatment vendor is a common mistake that many people make after they find out they have a water-quality problem. Water treatment is just one of several options that a homeowner has when water-quality problems exist in a private water system.

WHAT OPTIONS ARE AVAILABLE?

Once you know what contaminants are found in your drinking water and you understand how serious each is for the health of your family, you can make informed decisions regarding how to eliminate each from your water supply. This decision can best be made after you explore the following options:

Pollution control—Identify the source of pollution and eliminate it or divert it away from your drinking water supply. Many times a contamination problem may be caused by a pollution source existing near your water supply. Check the surrounding area and inspect your water system to ensure that the problem isn't something that can be removed with little effort.

Water system maintenance—Water-quality problems often arise because of water system neglect. Sometimes a little maintenance or an inspection by a qualified professional can provide an easy fix for a water-quality problem.

Water treatment—Almost any water-quality problem can be eliminated through the use of water treatment equipment. However, treatment equipment can be very expensive, and it is important that you be knowledgeable about what equipment is needed before seeking assistance from a treatment vendor. More information about water treatment can be found throughout this chapter.

New system development—After looking at all of the options available to you, it may be best to develop a new source of water. If it is possible to find a higher-quality water supply by drilling a new well, constructing a rainwater cistern, or hooking onto a nearby public water system, one of these may be a better alternative than buying several different types of treatment equipment, all of which have their own maintenance requirements.

The remainder of this chapter focuses on water treatment options for common water-quality issues. Water treatment is complex, requiring an understanding of basic treatment processes. However, do not underestimate the role of maintenance, controlling pollution sources, and new water source development in solving water-quality problems. Those are, generally speaking, better options if they are available.

HOME WATER TREATMENT IN PERSPECTIVE

Drinking water treatment equipment is gradually becoming commonplace in many homes and offices. A 2006-07 study found that about half the homes in Pennsylvania with a private water supply used some type of water treatment (Swistock et al. 2009). Ion exchange units, carbon filters, and countertop distillation units are among the systems used. Consumers can choose from two basic types of treatment: point of entry (POE) or point of use (POU). POE equipment is placed so that all water entering the structure is treated. POU equipment is strategically placed only where treated water is desired, such as the kitchen sink.

The rise in popularity of water treatment devices is evidenced by the growth in the water treatment industry, which has become a major industry in the United States. In fact, current manufacturers design, produce, and market a wide variety of treatment devices that promise to provide cleaner, purer, or safer water. While many water treatment manufacturers are reputable companies concerned about consumer welfare, some manufacturers prey on the buyer's ignorance or apprehension and use misleading advertising techniques to sell their products.

Home water treatment can be confusing and expensive. This section is provided to help answer some common questions about when and how to purchase treatment equipment.

MISCONCEPTIONS ABOUT HOME WATER TREATMENT

Misconceptions about home water treatment arise out of a combination of false advertising, consumer myths, and misinformation. They are perpetuated by nonuniform testing standards and a lack of product certification requirements.

Let's take a look at common advertising and selling strategies used by some POE-POU treatment manufacturers. First, companies advertise with misleading or even false statements such as "a device that is your only solution to purer water . . . a device that produces water like God made in the beginning . . . water that will make your hair more silky and manageable . . . healthier water." Sometimes generalized statements are made about all units when they apply only to a particular model. These strategies mislead buyers into believing that a device is the answer to *all* their water-quality problems.

Another common selling technique for water treatment equipment is the use of door-to-door "water specialists." These salespeople run a "free" test on your water and use colorful charts to show how their devices remove the contaminants discovered in your water. They tell you about phony national surveys, special trips you can win, and the contaminated, detrimental condition of the water flowing from your very own kitchen sink. Their presentation usually ends with a final sales pitch to coerce you into "making a decision today that will keep you healthy for the future."

Consumers plagued by exaggerated health fears or misinformation are easy prey for such hard-sell techniques. The environmental and health information readily available to the public in newspapers, magazines, and documentaries often enlarges the risk of certain chemicals and puts doubt in consumers' minds about just how safe their water is. If a test reveals the presence of a particular contaminant, many homeowners view water treatment as a quick fix. Then, without knowing which devices are intended for which problems, they seek help from a "professional" who sells them the wrong equipment. To further complicate the situation, a buyer often is not made aware of equipment maintenance requirements or warranties. As a result, the device fails to remove contaminants and, in some cases, may actually introduce other contaminants into the water supply.

Unfortunately, another common misconception that permeates the POU-POE treatment industry is that water treatment equipment is the only solution for water-quality problems. As mentioned earlier, this is not always the case and homeowners should research all solutions before settling on water treatment.

What Can You Do?

Today, almost any water-quality problem (both nuisance and health based) can be fixed by purchasing the appropriate equipment. However, homeowners with private water systems are often uninformed about water treatment processes and equipment, making them susceptible to unscrupulous businesses selling treatment equipment. The following tips will assist you in considering the purchase of water treatment equipment.

Understand the Water-Quality Problem

If you suspect you have a problem with your water, make sure to have it tested by an *unbiased state-certified water-testing laboratory*. A list of state-certified water-testing laboratories is available from your local Pennsylvania Department of Environmental Protection office, online at water.cas.psu.edu, or at your county Penn State Cooperative Extension office. If test results from a certified laboratory show that your drinking water failed a primary, health-based drinking water standard, such as that for bacteria or lead, you should take action to correct the problem to protect your health and that of your family. Other water tests may indicate a problem from a secondary pollutant such as iron or manganese. In this case your health is not at risk, but you may choose to install water treatment equipment to reduce stains, tastes, or odors these pollutants can cause.

Consult Unbiased Water-Quality Experts

After receiving your test results from the certified water-testing laboratory, it is a good idea to go over the results with an unbiased water-quality expert. Unbiased experts may be available from the water-testing laboratory or from your county extension office. They can help you interpret the test results and provide advice on options for fixing any water-quality problem.

Match Treatment to Problem

Once you have decided that treatment is the best solution to your problem, learn about each of the basic water treatment processes and the pollutants they remove. Become an educated consumer and know which treatment devices will solve your problem before you approach treatment vendors. Table 5.1 provides information on the most common water treatment processes.

Research Treatment Companies

Always seek reputable water treatment companies that will provide you with local customer references. Research the company's history and look for those that have been established in the area for several years. Fly-by-night operations are common in the water treatment business, and you want to avoid them.

Beware of Hard-Sell Techniques

As discussed earlier, some water treatment vendors may use colorful home water tests or other methods to scare or pressure homeowners into buying water treatment equipment on the spot. Be cautious of companies using this strategy. Never make quick decisions. Confirm home water test results through an independent lab. Take your time and consult with other experts and other treatment vendors to get second and third opinions.

Ask About Maintenance Requirements

Purchasing water treatment equipment can be expensive and can be complicated by regular maintenance required for the equipment. Make sure you fully understand the maintenance requirements of all equipment before you buy. All water treatment equipment requires routine maintenance. Sometimes this maintenance is simple, such as replacing a faucet carbon filter or ultraviolet light bulb. In other cases, maintenance is more involved, such as regenerating oxidizing filters or replacing membranes in reverse osmosis units. It is best to understand the details of treatment equipment maintenance before you buy. Determine what maintenance will be done by the treatment company and what your responsibility will be.

Table 5.1. A summary of common water treatment processes used in Pennsylvania.

Treatment method	Primary uses	Type of unit[1]	Notes
Acid neutralization	Corrosive water, copper, lead, pinhole leaks in plumbing	POE	Uses limestone chips or soda ash to increase water pH and hardness to prevent corrosion. Never combine with softener.
Activated alumina	Arsenic, fluoride	POE or POU	Water pH must be less than 8.5. Pretreatment with oxidation may be necessary to achieve good arsenic removal.
Aeration	Hydrogen sulfide, methane, volatile organics, radon	POE	Expensive and susceptible to clogging by other pollutants, but very effective when multiple gases are present. Requires disinfection treatment.
Anion exchange	Sulfate, nitrate, arsenic	POE or POU	Increases chloride concentration in treated water. May make water more corrosive.
Carbon filter	Chlorine, pesticides, herbicides, radon, miscellaneous tastes and odors, human-made volatile organics, limited removal of hydrogen sulfide odor	POE or POU	Disinfection should be used on water supplies with bacterial contamination because bacteria can multiply in filter. Carbon must be periodically replaced when exhausted.
Chlorination	Bacteria, hydrogen sulfide, iron	POE	Water must be clear for chlorine to work. Must also provide a tank for storage and contact time. pH adjustment may be necessary.
Distillation	Removes everything *except* volatile organics, pesticides, herbicides	POU	Produces small amounts of bland-tasting water. Space needed to store treated water.
Oxidizing filters	Iron, manganese, hydrogen sulfide	POE	Periodic addition of chemicals is necessary along with backwashing. Good option when two or all three pollutants are present.
Ozone	Bacteria, metals, odors, tastes	POE	Expensive to purchase and operate but very effective at removing multiple pollutants.
Reverse osmosis	Removes any dissolved pollutants from water	POU	Produces small amounts of water and produces some waste water. Does not remove most organic pollutants or bacteria.
Sediment filters	Soil, sand, other particles. Certain types can also be used to remove *Giardia* cysts	POU or POE	Must be routinely changed (POU) or backwashed (POE) to maintain water flow.
Softeners	Removes hardness (scale) along with limited amounts of dissolved iron	POE	Causes increase in water sodium level. Use potassium salt or only soften hot water if on a low-sodium diet. Water may become more corrosive after softening.
Ultraviolet light	Bacterial disinfection	POE	Water must be free of sediment to kill bacteria effectively. Bulb must be changed annually.

[1] POU = point-of-use treatment device used to treat the water at one faucet or tap where the water is used. POE = point-of-entry treatment device used to treat all of the water as it enters the home.

Look for NSF and WQA Certifications

Several independent associations provide testing of water treatment equipment to determine its effectiveness. Two such organizations are the National Sanitation Foundation (NSF) and the Water Quality Association (WQA). Ask water treatment vendors to provide written proof of these certifications for their equipment. Note that EPA certification does not ensure that equipment will remove certain pollutants.

Costs of Water Treatment Equipment

Costs of water treatment equipment vary considerably depending on the type of unit, size, pretreatment requirements, and installation. Small faucet or pour-through carbon or activated alumina filters often cost less than $20. Other countertop or faucet point-of-use (POU) devices such as reverse osmosis and distillation units can cost $300 to $2,000, depending on the amount of water they produce per day. Most larger, whole-house point-of-entry (POE) filters, such as softeners, anion exchange units, carbon filters, oxidizing filters, and acid neutralizing filters, cost $500 to $1,500. Ultraviolet light disinfection systems can range from $400 for a basic unit to more than $1,000 for one with a light intensity sensor, sleeve cleaner, and automatic shut-off. Aeration and ozonation are usually the most expensive systems, costing several thousand dollars. According to the 2006-07 Penn State survey, homeowners reported spending on average about $1,300 on water treatment equipment and installation (not including upkeep) (Swistock et al. 2009).

Final Thoughts...

Approach any water treatment purchase carefully after receiving a water test report from an unbiased source. Get multiple estimates from reputable companies. Once you have made a decision, get everything in writing including a detailed warranty and maintenance agreement.

The following section gives a brief explanation of common water treatment devices and the contaminants they remove. Consult your county extension office or the Pennsylvania Master Well Owner Network at mwon.cas.psu.edu. Or e-mail mwon@psu.edu for more assistance.

COMMON WATER TREATMENT METHODS

Acid Neutralizing Filters

Acid-neutralizing filters are simple water treatment units intended to increase pH and add calcium, thereby decreasing corrosivity. They consist of a tank filled with calcium carbonate (limestone) chips, marble chips, magnesium oxide, or other alkaline material. Since corrosion affects the entire plumbing system, these treatment devices are installed where the water enters the home to treat all of the household water (point of entry, or POE). They are usually installed after the pressure tank. Raw water flows through the tank and as it contacts the media, its pH is increased and corrosivity decreased. Note: This process increases the water's hardness, but this is necessary for proper corrosion control. Also, the resistance of the neutralizing material may lower water pressure.

Frequent maintenance is required for neutralizing filters. The tank must be routinely refilled with neutralizing material as it is dissolved. The rate of refilling can range from weeks to months depending on the raw water corrosivity, water use, and the type of neutralizing material. Backwashing is recommended to remove trapped particles and oxidized metals unless a sediment filter is installed ahead of the unit.

Aeration Units

Home aeration units expose water to air so that contaminants like volatile organic chemicals and dissolved gases, such as radon, hydrogen sulfide, and methane, can be removed. These systems treat all of the water entering the home and range from simple systems, with spray aerators enclosed in a tank, to packed tower aerators, which collect and release the accumulated gas. Home aeration units are expensive, usually starting at around $3,000. This figure doesn't include installation or maintenance costs.

A spray aeration unit sprays contaminated water into the tank using a spray nozzle. The increased surface area of the sprayed water droplets causes the pollutant to volatilize while the air blower carries the contaminated air to a vent outside the home. To keep a supply of treated water, at least a 100-gallon holding tank usually must be used.

Packed-column aeration units allow water to move in a thin film over inert packing material in a column. The air blower forces contaminated air back through the column to an outdoor vent.

In a shallow-tray aeration unit water is sprayed into the tray and then flows over the tray as air is sprayed up through tiny holes in the tray bottom. The treated water collects in the tank bottom and is pumped to the water pressure tank. Advantages of this type of aeration include no fouling problems in tray holes, and the small size of the unit. However, this system requires larger amounts of air compared to the others.

Aeration systems are sometimes used to remove volatile organic compounds from industrial or fuel spills, but they are most often chosen for the removal of radon, hydrogen sulfide, or methane gases.

With new technological advancements in home aeration, the EPA has listed aeration as the best available technology for removing radon from water. Aeration units can have radon removal efficiencies of up to 99.9 percent. They are also ideal for high waterborne radon levels. Be aware, however, that to date neither the National Sanitation Foundation or the Water Quality Association has tested these units.

In comparison to chemical methods that might be used for hydrogen sulfide gas treatment, aeration may be advantageous because it does not add chemicals to the water. Maintenance costs are low for aeration units, but the initial purchase costs are often higher than other treatment options. Aeration is not usually efficient enough to remove all of the offensive odor at high hydrogen sulfide concentrations; thus, it is normally not used when hydrogen sulfide concentrations exceed about 2 mg/L. Sometimes aeration forms sulfur particles that must be filtered from the water. Disinfection of aerated water is recommended.

If aeration is used for methane removal, the aeration units should be placed if possible in a separate building where the methane is vented from the water before entering your home. In some cases, this is done by pumping the well into a buried cistern or storage tank that can be vented or aerated outside the home. Installing aeration devices in your basement with a vent leading outside is a less desirable alternative. Aerated water requires disinfection before use.

Ion Exchange (IE)

IE for anions such as nitrate, sulfate, and arsenic is similar to the process used in conventional water softeners, only anions (negatively charged ions) are being exchanged instead of cations (positively charged ions). These systems can be used to treat all the water entering the home, or they can be set up to remove contaminants from water used only for drinking and cooking.

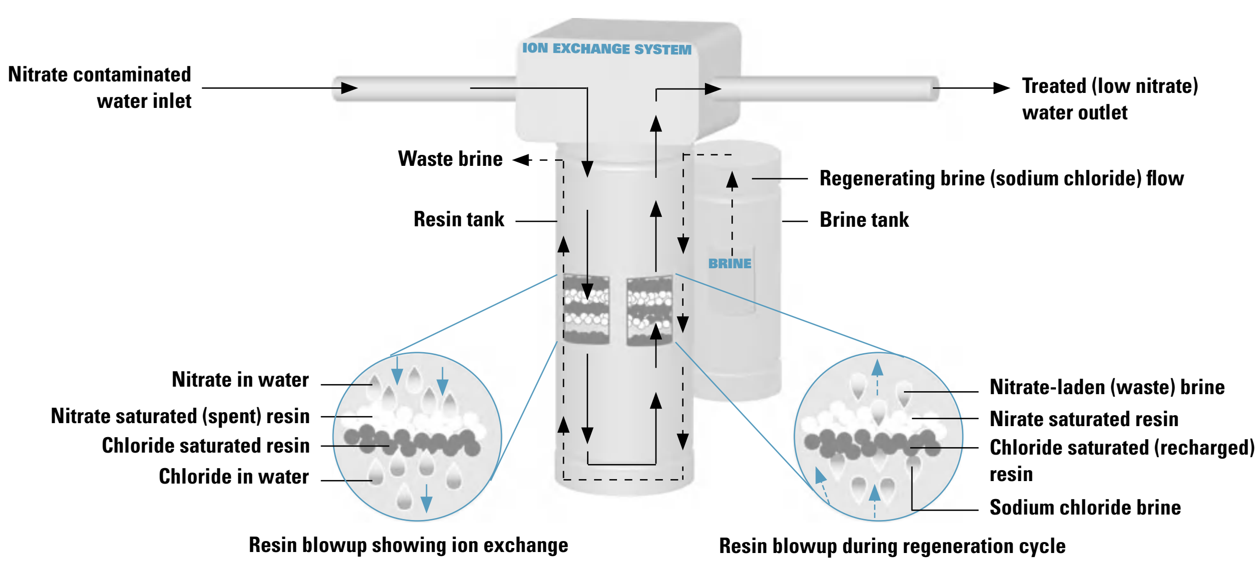
These units consist of a tank filled with resin beads coated in chloride. As water passes through the unit, the anions (such as nitrate, sulfate, or arsenic) adsorb to the resin, and chloride leaves with the treated water.

For nitrate removal, the resin exchanges chloride ions for nitrate and sulfate ions in the water. After treating many gallons of water, the resin "runs out" of chloride. Regenerating the resin with a concentrated solution of sodium chloride (you can use bicarbonate instead of chloride) recharges it for further treatment. Figure 5.1 shows how the anion exchange process works.

Anion exchange does have drawbacks. Because the resin prefers sulfate exchange, sulfates are exchanged before nitrates, thus, high sulfate water reduces system effectiveness. When the resin becomes saturated, it releases nitrates, resulting in an increased nitrate concentration in the "treated" water. Also, nitrate ion exchange can make the water corrosive. Neutralizing the water after it leaves the unit reduces this effect. Finally, ion exchange can be expensive and requires maintenance. Since the backwash brine is high in nitrates, care must be given to its disposal.

IE for arsenic removal works much like the nitrate system. Arsenic in the water is removed and chloride is added to the water in its place. Sulfate, total

Figure 5.1. Anion exchange unit showing nitrate removal and regeneration.



dissolved solids, selenium, fluoride, and nitrate all compete with arsenic and can reduce the efficiency of arsenic removal. Suspended solids and precipitated iron can also clog the IE unit and may require pretreatment. IE is usually a whole house POE device that treats all of the water entering the home. IE resins can be regenerated with much less dangerous chemicals than the activated alumina filter, but IE may increase water corrosivity by removing alkalinity. Neutralization may be required as an additional treatment to reduce corrosivity.

Cation Exchange (Water Softening)

Once water hardness is known, you have two options. You can live with the hardness level, recognizing that levels below 7.0 grains per gallon (gpg) will probably not cause major scaling and soap film, or treat the water to reduce the calcium and magnesium present. A water softener, which is a cation exchange unit, will effectively accomplish the latter option.

Because water-softening devices have long been available in the water treatment industry, the technology is highly developed and in most cases works well to reduce the hardness level. Water softening is a chemical process that filters the water through an exchange media known as resin or zeolite. Typically, the resin is a synthetic or natural, sandlike material coated with positively charged sodium ions. As the calcium and magnesium dissolves into positively charged ions, an ion exchange environment is created. The water flows through the unit while the resin releases its sodium ions and readily trades them for the calcium and magnesium ions. The water flowing out of the device is now considered soft.

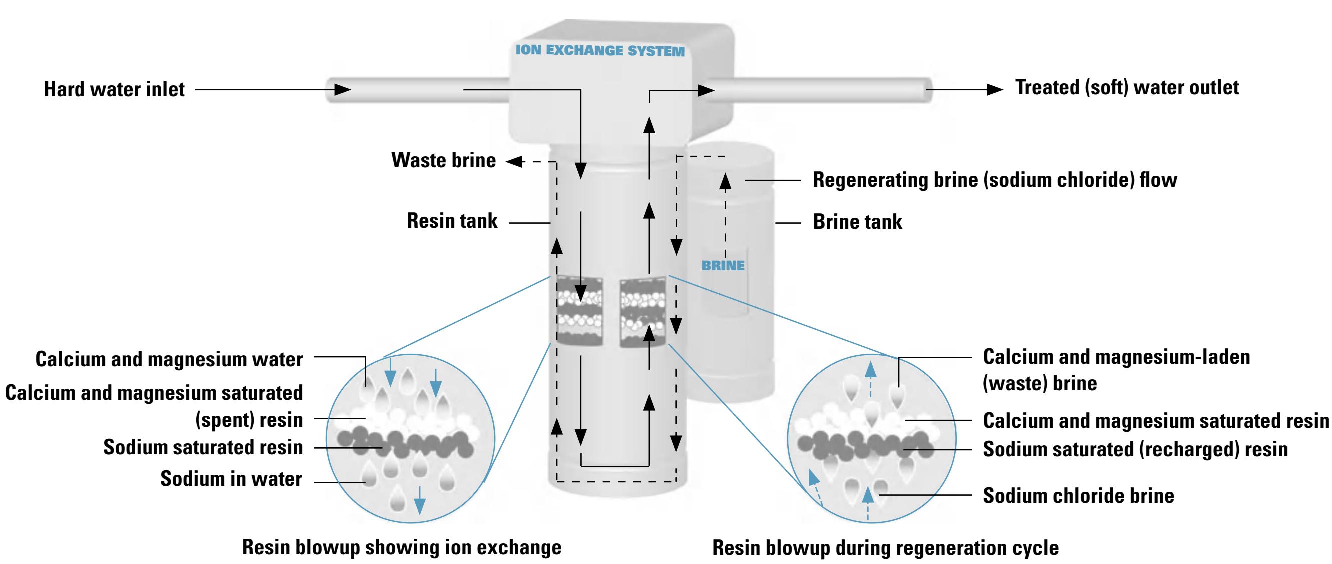
Regeneration

Clearly the resin is not an inexhaustible exchange site. When all the sodium exchange sites are replaced with hardness minerals, the resin is spent and can no longer soften water. At this point, the water softener needs to be run on an alternate cycle called regeneration. During this cycle, resin is backwashed with a salt solution. The brine is reverse flushed through the system, taking with it the calcium and magnesium ions that had been adsorbed on the resin. Once backwashing is complete, the softener can be returned to use. Some water softeners automatically switch to the operation cycle. Others have a manual switch. Figure 5.2 illustrates both cycles of the water-softening process—ion exchange and regeneration.

Kinds of Softeners

Although many brands and models of ion exchange units exist on the market, all essentially perform the same with minor differences in extra features, flow rates, etc. Nearly all softeners fall into one of two categories. Timed models have programmable time clocks that regenerate on a predetermined schedule and then return to service. These work well for households on regular water-using cycles but use more water and salt because they regenerate whether the resin needs it or not. Demand-control models, with either electrical or mechanical sensors, usually regenerate after so many gallons of water have been softened. Such models are convenient if you have a fluctuating water-use schedule.

Figure 5.2. A typical water softener showing cation exchange and regeneration.



Maintenance

No matter which model you choose, all water softeners need to be properly maintained. The brine solution must be mixed and stored in the brine tank. Periodic clogging of the resin also requires special attention. For example, if the raw water supply is turbid it may clog the resin with mud and clay. Sometimes normal backwashing with water solves this problem. If not, slowly stir the resin during the backwash cycle to help break up the material. Likewise, bacteria and fungi also form mats in the resin, reducing its effectiveness. Disinfecting the water before softening or periodically cleaning the softener with chlorine bleach eliminates these nuisances. However, read the manufacturer's instructions before adding any chemicals to the unit.

Iron fouling is another common maintenance problem for water softeners. Although colorless, reduced iron is removed by the unit, red-oxidized iron (iron that has been exposed to air or chlorine) clogs the resin. Filtration prior to softening ensures that oxidized iron is not processed in the softener. If the resin has already been fouled, commercial cleaners are available. Again, it is advisable to check the manufacturer's instructions for special precautions.

In some instances, resins cannot be washed of contaminants and need to be replaced. (This should *not* be the case if the resin is periodically regenerated and maintained.) Consult your water softener dealer for information on resin replacement.

Costs

Water-softening costs depend on factors such as installation, maintenance fees, and size of the unit. You can also expect that with more convenience features, the price of the unit will increase. An average range for the hardware only is around $500–$1,500.

Advantages and Disadvantages of Water Softening

As the water treatment industry has grown in the United States, the concept of water softening has often been misconstrued as a purifying, cleansing, or conditioning process. This is due largely to exaggerated advertising and, in part, to consumer misconceptions about water treatment. But the reality is that water softening simply removes hardness minerals and eliminates problems that are a nuisance and not a threat to human health. The decision "to soften or not to soften" is a matter of personal preference—not necessity. However, water softening does have advantages and disadvantages that make this decision a significant one.

Advantages

Most consumers would agree that hard water leaves scales on pots, soap films on skin, and detergent curds in the washing machine. More important, scales can also build up on hot water heaters and decrease their useful life. Soap film and detergent curds in bathtubs and appliances indicate that you are not getting the maximum cleaning action from these products. Soft water not only eliminates these nuisances but also protects appliances and saves cleaning time.

Water softening has other advantages, in addition. It is a well-developed technology that has been used in homes for almost 65 years. The equipment is reliable, effective, and widely available, providing consumers with convenient features and a selective market. The simple technology of softening makes it easy to bypass toilets and outdoor faucets. Finally, softening systems are adaptable for mixing softened and unsoftened water to produce a lower hardness level.

Disadvantages

The major disadvantage of water softening is the potential health risks for people on low-sodium diets. The exchange of hardness minerals for sodium adds 7.5 milligrams per quart for each gpg of hardness removed. In addition, calcium and magnesium are eliminated from the homeowner's diet. This disadvantage can be limited by using potassium salt instead of sodium salt or by only softening hot water and allowing drinking water to be unsoftened.

Maintenance is another consideration. While you can purchase models with special features that do everything but add the salt, you will pay for each additional feature. The trade-off is cost for convenience and you have no long-term guarantee that the special feature will not fail. Depending on the water source, you may have to filter turbid water or disinfect bacteria-laden water—all before it even reaches the softening unit. Finally, if you own a septic system, consider the additional load on your drainage field from backwashing and regeneration. Estimates indicate that about 50–100 gallons of water are used for each regeneration cycle. This may or may not cause hydraulic overload of the septic system.

Shock Disinfection (One-Time Chlorination)

While the following is provided as an overview to inform the homeowner about proper well chlorination, it is strongly recommended that you contact a professional well contractor to effectively and safely perform this procedure for you due to the variable nature of individual wells and water systems.

Bacterial contamination is one of the most common water-quality problems in private water wells and springs. A recent survey of 700 private wells in Pennsylvania found that about 33 percent contained coliform bacteria. Past studies have shown that springs are even more susceptible to bacterial contamination. These bacteria are a potential problem because they may cause serious gastrointestinal illnesses (see Chapter 4). Shock chlorination can be used to disinfect a well or spring that has become contaminated from a one-time incident such as flooding or a dead animal in a well or spring box.

Water Treatment Equipment Concerns

Before shock chlorinating your water system, it is important to determine if any susceptible water treatment equipment, such as a softener, carbon filter, or a reverse osmosis system, is installed in your home. Some water treatment equipment can be damaged or exhausted by high chlorine concentrations in water. Contact your water treatment company or equipment manuals to find out if your equipment should be bypassed during shock chlorination.

When to Shock Chlorinate Your Well or Spring

Shock chlorinate your well or spring:

- After constructing a new well (many well drillers do this as a standard practice)
- After working on an existing well or installing a new submersible pump
- After receiving a positive water test report for coliform bacteria

Disinfection Procedure for Wells

Take the following steps to disinfect a well:

1. *Clear the water:* If your water is cloudy or contains any suspended particles, the well should be pumped until the water clears. Cloudy water greatly reduces chlorine's ability to kill bacteria.
2. *Obtain chlorine:* Unscented household chlorine bleach containing 5.25 percent available chlorine may be used to shock chlorinate private water supplies; however, only chlorine products with label information specifying use in potable water supplies can be recommended. These must be obtained from water treatment vendors or well drilling contractors. Consult Table 5.2 to determine the amount of bleach you will need for your well. Note that the water depth shown in the table refers to the actual depth of water in the well, not the total depth of the well.

   In some cases, it may be difficult to determine the actual depth of water in the well. This information may be stamped on the inside of the well cap or written on the well completion report you received from the well driller. If you are unable to determine the actual depth of water in the well, use a minimum of 0.5 gallon of bleach if you estimate the water depth to be less than 80 feet and the well diameter is 8 inches or less. For wells with greater water depth and diameter, use 1 gallon of bleach. *It is always better to use too much chlorine than too little!*

Table 5.2. Amount of household bleach required to disinfect a water well.

	Water diameter (inches)					
Water depth (feet)	6	8	10	24	32	36
10	1 c	1 c	2 c	3 qt	4 qt	6 qt
20	1 c	2 c	4 c	5 qt	8 qt	10 qt
30	2 c	4 c	3 pt			
40	1 pt	2 pt	4 pt			
60	2 pt	3 pt	6 pt			
80	2 pt	4 pt	7 pt			
100	3 pt	5 pt	4 qt			
150	5 pt	4 qt				

c = cup, pt = pint, qt = quart

3. *Apply chlorine to well:* Remove the cap from the top of the well and mix the chlorine with 5 to 10 gallons of water in a nonmetallic container. Be careful to keep the chlorine solution away from your skin and clothing. Slowly pour this solution into the well. Remember to bypass any sensitive water treatment equipment before proceeding. It is recommended to turn off the power to the pumping system for safety before beginning this procedure and to turn the power back on when completed. Also, be aware of wiring connections at the wellhead. It is best not to pour the chlorinated water directly onto any wiring connections or splices.
4. *Mix chlorine within well:* To adequately mix the chlorine solution in the well, run a garden hose from an outside faucet into the well and circulate water into the well, washing down the sides of the casing until a strong odor of chlorine occurs in the water from the hose. It may take from 15 minutes to 1 hour for enough mixing to occur. (Note: If a strong chlorine odor is not noticeable at the hose after thorough mixing, too little time was allotted or not enough chlorine was added to the well—more chlorine should be added.) Close the hose faucet and replace the well cap.
5. *Turn on inside faucets:* Inside the home, turn on each faucet throughout the house (one at a time) until a strong chlorine odor is noticeable in the water. You should run both the cold and hot water at each faucet until you notice the strong chlorine odor. (Note: It may take quite some time for a

chlorine odor to be noticed at the first cold and hot water faucet that is turned on, owing to the significant volume of the hot water heater.) Once the odor is noticeable, turn off the faucet. This will ensure that the chlorinated water has been dispersed throughout the plumbing system. If a strong chlorine odor is not apparent at any of the faucets, more mixing may need to occur or more chlorine should be added to the well (see step 4 above).

6. *Provide contact time:* Allow the water to sit in the plumbing for at least 12 hours.

7. *Purge high-chlorine water from the well:* The first water used following shock chlorination is of a chlorine concentration similar to that used for bleaching laundry. The first water may also appear very discolored owing to iron or other metals from the well casing or in the water. Disposal of this high-chlorine water must be done carefully. If your home is connected to a central sewer system, you can dispose of the water by letting each of the faucets in the home run until the chlorine smell dissipates to an acceptable level. Note that complete removal of the chlorine smell may take several days of normal water use. Do not use water that has a strong chlorine odor for bathing, cooking, washing, or drinking. This water may cause skin irritation and damage to clothing.

   If your house has a septic system, do not run all the chlorinated water into the system as it may overload the system. In this case, use a garden hose to pump some of the chlorinated water to a safe disposal site. Bare ground is the best disposal area, or the water can be sprinkled on grass. Avoid applying the high-chlorine water to foliage of flowers or ornamental shrubbery or near any water body containing fish.

8. *Retest your water:* After following the procedures outlined above, retest your well water for coliform bacteria approximately 10 to 14 days after the shock chlorination. If no coliform bacteria are present, wait an additional two to three months and have the water tested again. If the bacteria return in either of these subsequent tests, a continuous disinfection treatment system will be necessary.

Disinfection Procedure for Springs

Shock chlorination of springs is difficult and rarely successful because the water often runs through the spring box too quickly to provide adequate contact with the chlorine to kill bacteria. Disinfection of the spring box should not be attempted if the spring overflow (the water that does not enter the house) enters a stream, pond, or wetland area where high-chlorine water may cause environmental damage, especially a fish kill.

1. *Wash spring box walls:* Shock chlorination of a spring can be attempted by mixing 0.5 cup of household bleach with 5 gallons of water to scrub the walls.

2. *Disinfect spring box water:* Estimate the volume of water in the spring box in gallons (there are 7.5 gallons of water in each cubic foot of storage). For each 100 gallons of water in the spring box, create a disinfection solution by mixing about 3 pints of chlorine solution with a few gallons of water. Pour the disinfection solution into the spring box.

3. *Follow well disinfection steps 5–8:* Use steps 5-8 on the previous page to disinfect each of the faucets in the home and run the water to a disposal site the next day. Because of the prevalence of bacteria in springs and the difficulty in adequately shock chlorinating the spring source, installing continuous disinfection treatment equipment for spring sources with coliform bacteria is often necessary.

Continuous Disinfection (Continuous Chlorination)

Municipal water treatment plants throughout the United States continuously add chlorine to ensure that their water is free of bacteria. Chlorination treatment systems are basically composed of a feed system that injects a chlorine solution (sodium hypochlorite or calcium hypochlorite) into the water ahead of a storage tank. Most chlorinators use positive displacement feed pumps to meter the chlorine into the water. Other units may use suction-type chlorinators or pellet droppers to deliver the chlorine.

The raw water entering the chlorinator should be perfectly clear or free of any suspended sediment or cloudiness in order for the chlorine to effectively kill the bacteria. A sediment filter is routinely installed ahead of the chlorinator to remove small amounts of suspended material.

The chlorine that is injected into the water is consumed as it kills bacteria. The chlorine is also consumed by impurities in water such as iron, hydrogen sulfide, and organic materials. The amount of chlorine needed to kill bacteria and oxidize all the impurities in the water is known as the *chlorine demand.* Thus, the total amount of chlorine that must be injected into the water depends on the chlorine demand of the raw water. Other water characteristics such as pH and temperature also affect the amount of chlorine that must be injected into the water. The goal of continuous chlorination is to provide enough chlorine to satisfy the chlorine demand and still allow for approximately 0.3 to 0.5 milligrams per liter of residual chlorine in the water. This residual chlorine is then available to kill bacteria that may enter the water after the chlorinator.

The time required for the chlorine to kill bacteria is known as the *contact time*. The required contact time varies depending on water characteristics, but a general rule of thumb is to provide approximately 30 minutes of contact time. Standard pressure tanks are usually not large enough to provide sufficient contact time, so a larger intermediate holding tank may need to be installed. Sufficient contact time can also be achieved by running the water through a series of coiled pipes. Contact time requirements can be shortened by increasing the chlorine dose (superchlorination), but this may require the addition of a carbon filter to remove the objectionable chlorine taste and odor.

Continuous chlorination treatment systems require significant maintenance. Chlorinators must be routinely checked to ensure proper operation and chlorine supplies must be continually replenished. Both liquid and solid forms of chlorine are poisonous and irritants that must be handled according to specific safety measures.

Ultraviolet Light Disinfection

Ultraviolet (UV) light has become a popular option for disinfection treatment because it does not add any chemical to the water. However, UV light units are not recommended for water supplies where total coliform bacteria exceed 1,000 colonies per 100 mL or fecal coliform bacteria exceed 100 colonies per 100 mL.

The unit consists of a UV light bulb encased by a quartz glass sleeve (Figure 5.3). Water is irradiated with UV light as it flows over the glass sleeve. The untreated water entering the unit must be completely clear and free from any suspended sediment or turbidity to allow all of the bacteria to be irradiated by the light. In addition, inorganic constituents such as iron, manganese, and hardness can coat the glass sleeve and, thus, must be below certain specified levels for the UV unit to effectively treat the water. Check the manufacturer's recommendations to see if pretreatment is required before installing a UV unit.

A sediment filter is often installed ahead of the UV unit to remove any sediment or organic matter before it enters the unit. The quartz glass sleeve must also be kept free of any film. Overnight cleaning solutions can be used to keep the glass sleeve clean, or optional wipers can be purchased with the unit to manually clean the glass. Water with a high hardness (calcium and magnesium) may also coat the sleeve with scale (a whitish deposit of hardness), which may require routine cleaning or addition of a water softener. The unit also requires electricity and will cause a small but noticeable increase in your electric bill (perhaps $2 to $4 per month). The disadvantage of this system is that it only kills bacteria inside the unit and does not provide any residual disinfectant for bacteria that may survive or be introduced into the plumbing after the UV light unit.

Maintenance requirements are minimal for UV units, but the light bulb slowly loses intensity over time and requires replacement about once a year. Some units come equipped with a UV light intensity sensor that can detect when the bulb is not emitting sufficient UV light. These sensors add to the initial cost of the unit but may pay for themselves by preventing premature bulb replacement.

Oxidizing Filters for Removing Iron, Manganese, and Hydrogen Sulfide

Oxidizing filters both oxidize and filter iron, manganese, and hydrogen sulfide in one unit. The filter is usually comprised of manganese-treated greensand, although other materials such as birm can also be used. In the case of a manganese greensand filter, the filter media is treated with potassium permanganate to form a coating that oxidizes the dissolved iron and

Figure 5.3. A typical UV light installation with a small canister sediment filter ahead of the UV light unit.

manganese and then filters them out of the water. Because these units combine oxidation and filtration, they can be used to treat raw water with dissolved and/or oxidized iron and manganese along with hydrogen sulfide gas.

Manganese greensand filters require significant maintenance including frequent regeneration with a potassium permanganate solution. In addition, these units require regular backwashing to remove the oxidized iron and manganese particles. The potassium permanganate solution used for regeneration is toxic and must be handled and stored carefully using specific safety measures.

When properly maintained, manganese greensand filters are extremely efficient for moderate levels of both dissolved and oxidized iron and manganese. They are generally recommended when the combined iron and manganese concentration is in the range of 3 to 10 mg/L. Keep in mind that the frequency of maintenance (backwashing and regeneration) increases as the metals concentration increases. Oxidizing filters can be used to remove up to 2-3 mg/L of hydrogen sulfide. The higher the concentration of hydrogen sulfide, however, the more frequently the unit will need regeneration and backwashing.

Birm filters are similar to manganese greensand, but they do not require regeneration because they use oxygen present in the raw water to oxidize the metals. As a result, the raw water must contain a certain amount of dissolved oxygen, and the pH should be at least 6.8 for iron removal and 7.5 for manganese removal. Even under ideal conditions, manganese removal efficiency is highly variable with birm filters. Birm filters do require backwashing to remove accumulated oxidized metal particles.

When combined levels of iron and manganese exceed 10 mg/L, the most effective treatment involves oxidation followed by filtration. In this process, a chemical is added to convert any dissolved iron and manganese into the solid, oxidized forms that can then be easily filtered from the water. Chlorine is most commonly used as the oxidant, although potassium permanganate and hydrogen peroxide can also be used. A small chemical feed pump is used to feed the chlorine (usually sodium hypochlorite) solution into the water upstream from a mixing tank or coil of plastic pipe. The mixing tank or pipe coil is necessary to provide contact time for the iron and manganese precipitates to form. It may be necessary to install an activated carbon filter to remove the objectionable taste and odor from the residual chlorine. Chlorine is not recommended as an oxidant for very high manganese levels because a very high pH is necessary to completely oxidize the manganese.

Significant system maintenance is required for these units. Solution tanks must be routinely refilled and mechanical filters need to be backwashed to remove accumulated iron and manganese particles. If a carbon filter is also installed, the carbon needs to be replaced occasionally as it becomes exhausted. The frequency of maintenance is determined primarily by the concentration of the metals in the raw water and the amount of water used.

Ozonation

Ozonation eliminates bacteria, viruses, microorganisms, colors, odors, and tastes. It can oxidize iron, manganese, and hydrogen sulfide, and it can precipitate some metals.

In recent years, ozonation has received more attention as a method for treating water-quality problems including bacterial contamination. Like chlorine, ozone is a strong oxidant that kills bacteria, but it is a much more unstable gas that must be generated on site using electricity. Once the ozone is produced, it is injected into the water where it kills the bacteria. Ozonation units are generally not recommended for disinfection because they are much more costly than chlorination or UV light systems. They may be useful where multiple water-quality problems must be treated, such as disinfection in combination with removal of iron and manganese.

Ozonation does not typically require much maintenance, but the health implications for those using it are not fully understood.

Chemical Injection

Various chemicals can be injected into the water line to treat a variety of water pollutants. Continuous chlorination (described above) is one special type of chemical injection that is used to treat bacteria problems. Chlorine can also be injected to oxidize metals and hydrogen sulfide odor in water. Thus, direct injection of chlorine can be very efficient for treating metals, hydrogen sulfide, and bacteria when all are present in water. Chemical injection often involves the use of soda ash (for corrosion control), potassium permanganate (for metals and hydrogen sulfide), or polyphosphate (for iron).

Injection of soda ash or other basic solutions is sometimes used to treat extremely corrosive waters that exceed the capacity of standard acid neutralizing filters. This treatment system is simple and inexpensive and does not increase water hardness. Since the unit is installed ahead of the pressure tank, there is no reduction in water pressure that sometimes occurs with neutralizing filters. There is significant maintenance, including filling solution tanks and maintaining the feed pump. Soda ash is preferred over sodium hydroxide because it is safer to handle. Sodium hydroxide is extremely caustic and must be handled using accepted safety practices.

Another common chemical injection is potassium permanganate to treat hydrogen sulfide, iron, and manganese. Much like chlorination described above, a potassium permanganate solution can be injected into the water with a small chemical feed pump installed ahead of a holding tank that provides at least 15 minutes of contact time. The oxidized sulfur particles can then be removed using a manganese greensand or zeolite filter. The filter media also allows for polishing of unoxidized hydrogen sulfide (see "Oxidizing Filters"). Like chlorination, this method is excellent for high concentrations of hydrogen sulfide above 6.0 mg/L. However, the potassium permanganate solution is an irritant and poison that must be handled and stored according to standard procedures.

A final chemical treatment, in which the chemicals are often injected directly into water, is the use of polyphosphates to sequester dissolved iron concentrations less than about 2 mg/L. Phosphate addition is generally ineffective in treating manganese. The phosphate is fed into the water using a chemical feed pump that often requires trial-and-error dose adjustments. In this case, the iron is surrounded or "sequestered" by the phosphate and is not actually removed from the water.

This process has some major drawbacks. Although the sequestered iron does not cause objectionable stains, it still gives the water a metallic taste. In addition, if too much phosphate is added to the water, it gives the water a slippery feeling and may also cause diarrhea. The polyphosphate may also be degraded in a water heater, resulting in release of sequestered iron.

Activated Alumina

Activated alumina (AA) filtration involves the passage of water through an alumina media. Arsenate is very strongly attracted to the alumina material as the water passes through the filter. Large AA treatment devices or point-of-entry (POE) devices can be used to treat all household water, or smaller point-of-use (POU) filters can be used to remove arsenic at a single tap in the home. AA is the preferred treatment method if your water has high total dissolved solids (TDS) or high sulfate concentrations. A disadvantage of AA filters is that they must be regenerated using strong acid and base solutions that are undesirable for home storage and handling. In addition to periodic regeneration, the alumina filter material must be replaced every one to two years.

Granular Activated Carbon (GAC)

GAC is commonly used to treat many water pollutants because it has a large treatment surface that allows for many chemicals to be adsorbed and removed from water. Many small faucet filters are filled with a tiny amount of GAC that can effectively polish water to remove small amounts of objectionable tastes. The most common use of these small faucet filters is to remove chlorine taste and odor from water at one sink.

Larger, whole-house or POE GAC treatment units can be installed to remove many organic pollutants like fuel oil, gasoline, solvents, and pesticides. These filters are normally large fiberglass tanks filled with 1 to 2 cubic feet of GAC. When removing pollutants, the GAC has a limited lifetime as the carbon becomes spent by the incoming pollutants. The life of the carbon is related to the concentration of the pollutants in the water, the size of the carbon filter, and the amount of water put through the filter. You should periodically retest your treated water to ensure that your carbon filter is working properly. Generally speaking, GAC will need to be replaced about every six months under typical operating conditions. Keep in mind that removal of hazardous materials with a GAC filter produces a hazardous spent carbon material that must be disposed of properly. Contact your local Department of Environmental Protection office to learn how to safely dispose of a spent carbon filter.

Because of the carbon's fine particle size, it also easily clogs with sediments or other contaminants present in the water. Some GAC units come with a special backwashing feature for removing sediment. These eventually reduce the carbon's effectiveness in treating pollutants. Eliminating the sediment source or placing a sediment filter ahead of the GAC tank provides the best protection against clogging. Also keep in mind that GAC filters are an excellent growth media for bacteria. As a result, only disinfected water or water known to be free of coliform bacteria should be allowed through a GAC filter.

GAC is also a popular method for treating radon in water. Unlike other pollutants, radon does not consume carbon. Instead, the radon gas degrades in the filter. However, experts disagree on GAC's ability to treat radon in water. Some estimates show that it should not be used if waterborne radon levels exceed 30,000 pCi/l. Other experts say 5,000 pCi/l. The best way to decide is to have your water tested and then investigate GAC filters that have high removal efficiency rates at the level found in your water.

If you do decide to purchase a unit, select a filter size that matches water use and conditions. According to EPA, a 3-cubic-foot unit can handle as much as 250 gallons of water per day and effectively reduce radon levels. Typical water use in the home ranges from 50 to 100 gallons per person per day. Size and special features both affect costs, which can start at $700 depending on the unit. They can be purchased commercially through water treatment dealers. Be sure to investigate thoroughly the company and its products before purchasing any unit. GAC filters will remove radon indefinitely, providing that sediments or organic pollutants have not clogged the filter.

A major drawback to using GAC filters is that if radon is present, the filter becomes radioactive as it picks up the gas. Lead-210 (a radon daughter) builds up on the carbon filter and then gives off its harmful radioactive rays as it continues to decay. **IT IS EXTREMELY IMPORTANT TO PLACE THE UNIT OUTSIDE THE HOME OR IN AN ISOLATED PART OF THE BASEMENT. A SHIELD MAY BE REQUIRED IF RADON LEVELS ARE HIGH (GREATER THAN 30,000 PCI/L).**

GAC filters may produce a radiation problem when the device is used to remove other contaminants. For example, a homeowner installs a GAC unit to remove a pesticide without testing the water for radon. The GAC unit sits under the sink, harmlessly removing the problem contaminant. Right? Wrong. Unfortunately, what the homeowner doesn't know is that the water supply has very high radon levels. So while the GAC traps the pesticide it also traps radon, thus producing a radioactive filter and a radiation hazard.

GAC can also be used to remove small amounts (less than about 1.0 mg/L) of hydrogen sulfide gas from water. In most cases, GAC units are installed in combination with other hydrogen sulfide treatment (oxidizing filters, etc.) to "polish" the water and remove small amounts of residual hydrogen sulfide that are not removed during the primary treatment.

More recently, other forms of activated carbon known as "catalytic carbon" have been developed for hydrogen sulfide treatment. Catalytic carbon first adsorbs the hydrogen sulfide then oxidizes the gas much like an oxidizing filter. As a result, catalytic carbon units can be used to treat much higher hydrogen sulfide concentrations than activated carbon filters. Maintenance requirements are less than oxidizing filters because no chemicals are added, but backwashing is still necessary. Catalytic carbon requires a minimum of 4.0 mg/L of dissolved oxygen in the source water. Some groundwater supplies may need pretreatment to increase the dissolved oxygen concentration.

Distillation

Distillation is an older method of removing contaminants from drinking water. It involves boiling water, collecting the steam, and allowing it to cool. The treated water resulting from this process is free of most contaminants. Distillation can be used to disinfect water, remove many organic and inorganic contaminants, and reduce the concentration of toxic metals. Distillation completely removes from the water all dissolved solids, which may affect the water's taste and make it more corrosive.

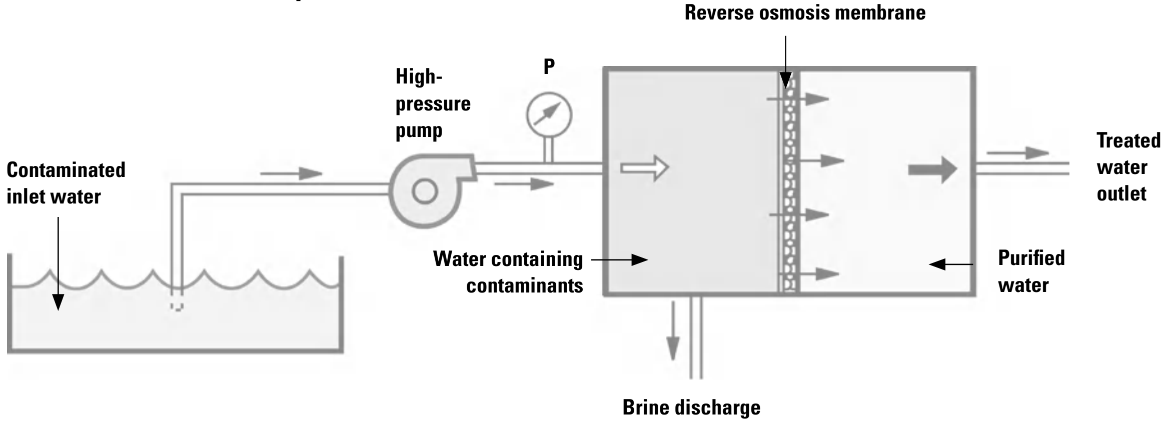
It is difficult to determine the maintenance schedule for a distillation unit until it is installed. The quality of the water being treated will determine how often it needs maintenance. Other considerations include the costs associated with using more electricity; in addition, these units produce a considerable amount of heat and do not remove certain volatile chemicals.

Reverse Osmosis

Reverse osmosis is another common treatment that can effectively remove most inorganic pollutants (such as arsenic, barium, cadmium, chloride, copper, fluoride, lead, manganese, mercury, and nitrate). Figure 5.4 shows the reverse osmosis process. As water enters the unit under pressure, it pushes against a cellophane-like plastic sheet or cellulose—also called a semipermeable membrane. The membrane acts like a sieve, leaving ions on one side and allowing ion-free water to pass through the membrane. How well the membrane filters the water is measured by the rejection rate.

While a simple reverse osmosis filter includes just a storage tank and a membrane, other treatment processes are usually included in the overall reverse osmosis device. For example, a sediment filter is often added to remove particles before the water encounters the sensitive membrane, and an activated carbon filter is often included after the membrane to polish the water and remove trace pollutants that may still

Figure 5.4. The reverse osmosis process.



impart tastes or odors to the water. As a result, the overall reverse osmosis unit often appears as three filters (sediment, membrane, and carbon filters). Units usually operate at the point of use—kitchen tap, bathroom sink, etc. Many factors like water pressure and temperature, membrane selection, and proper maintenance influence performance. Carefully review these factors with a water specialist before making purchasing decisions.

While reverse osmosis can be effective at removing many inorganic pollutants, it has disadvantages. Reverse osmosis is expensive, with initial costs ranging from $300 to $900. Added to the equipment costs are the high energy costs for operation. Reverse osmosis is also a slow, inefficient process, sometimes producing only a few gallons a day of purified water, while wasting up to 90 percent of the incoming water. This is especially true for low pressure systems.

Other Treatment Options

Boiling (Disinfection)

Boiling water for about one minute effectively kills bacteria. This method is frequently used to disinfect water during emergencies or while camping. Boiling is time and energy intensive, however, and only supplies small amounts of water. It is not a long-term or continuous option for water supply disinfection.

Water System Flushing (Lead or Copper)

Excessive amounts of lead and/or copper in water from corrosion of metal plumbing can sometimes be avoided through water system flushing. This flushing simply involves running the water from the faucet for a minute or two to purge the contaminated water from the plumbing and draw fresh, unpolluted water in from the well or spring. This can be effective because corrosion of copper and lead normally takes an hour or more to build up as the water sits in contact with the metals.

Flushing is only necessary if the water has been in contact with the plumbing for at least one hour. If you choose this method, you should collect a water sample after you have run the water for one minute and have it analyzed for copper and lead to ensure that they are reduced to safe concentrations. You can conserve water by flushing the plumbing system in the morning and filling a container with drinking water for use during the day. Flushing can be a simple and inexpensive solution for excessive lead and copper in drinking water. But keep in mind that the continual corrosion of metal plumbing may ultimately cause leaks to develop in the pipes. If this occurs, other corrosion treatment (acid neutralizing filter, soda ash injection, etc.) or replacing the metal plumbing with approved PVC plastic is necessary.

Water Heater Adjustment (Hydrogen Sulfide)

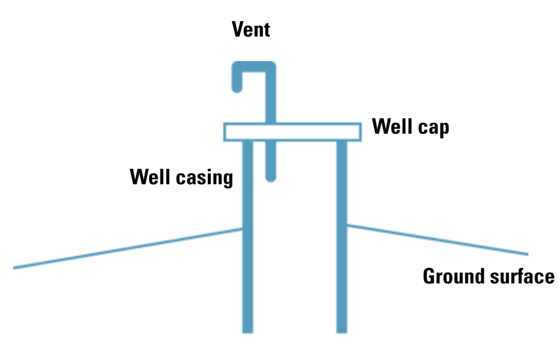
If the rotten egg odor occurs only in the hot water, the production of hydrogen sulfide can often be simply treated by removing the magnesium rod from the hot water heater. This rod often provides a chemical catalyst for the production of hydrogen sulfide from naturally occurring sulfates in the water. The magnesium rod is present in the hot water heater as an anti-corrosion device. Removing it could increase corrosion and reduce the life of the hot water heater, and will likely void the manufacturers' warranty. Replacing the magnesium rod with an aluminum rod should eliminate the rotten egg odor while maintaining corrosion protection for the heater.

Well Vents (Methane Gas)

Inexpensive vents can remove methane from some groundwater wells. A variety of vented caps are available from most well drillers for less than $100. Be sure to install these caps correctly to prevent insects and small animals from entering the well. Most have a screen and are turned down (see Figure 5.5).

If the well cap is buried or in a covered pit, the casing should be extended above the ground surface and subsequently be fitted with a cap and vent. Basement wells are especially problematic because the methane escapes directly into your home. You must fit the well with a sealed cap to prevent this leakage. The vent should then extend through the basement wall to the exterior of your house. Similarly, a vent can be installed on the pressure tank to allow methane gas to be removed and vented to the outside of the home. Local plumbing codes may include venting requirements. Contact a water-well professional to determine the best method.

Figure 5.5. Removal of methane gas using well vents.



Sediment Filtration (Various Contaminants)

Sediment filters come in many sizes and varieties. The simplest are very small cartridge filters commonly installed ahead of ultraviolet lights and other treatment units to remove sediment that might interfere with these treatment processes. These simple, inexpensive cartridge filters remove large sediment and metal particles, but they have very limited capacity.

Larger POE sediment filters are also available to treat much larger amounts of water and remove much smaller particles from water. They may even be constructed of very fine media that trap small particles like bacteria, cysts, and sediment. Sand, diatomaceous earth, spiral wound fiber, ceramic, and activated carbon are five common media used for filtration.

Although filters are widely believed to be a failsafe treatment, they are ineffective unless properly maintained and operated. Large sediment filters must be routinely backwashed to clean and restore their filtering capacity, while small cartridge filters must be replaced. The frequency of backwashing or replacement is often determined through trial and error. As sediment filters become saturated, water pressure is reduced to the home as water has a tougher time flowing through the filter. Once water pressure is noticeably reduced, you can conclude that backwashing or replacement is necessary.

As mentioned in the discussion on GAC filters, all sediment filters are excellent media for bacterial growth. If undisinfected water is used, filters are susceptible to bacterial growths that plug and coat the filters, reduce the filtering capacity, and create a source of contamination. For this reason, only disinfected water should be filtered. Filters must also be cleaned regularly and replaced. Filters such as the tap-mounted type must be changed at least every six months. Read the manufacturer's instructions to make sure that you are properly maintaining your filter.

Magnetic Devices (Not Recommended)

Typically these devices are permanent magnets or electromagnets that attach to waterlines entering homes and businesses to "purify" or "condition" water supplies. Manufacturers adopt a variety of commercial names for their products from the complex—"patented directional controlled magnet," "Permcore," and "Magnetizer"—to the simple—"metal bar" or "plug-in treatment device."

Such devices purportedly use electromagnetic fields to change the molecular makeup of various water constituents like calcium and iron to other more "inert" forms. The claimed result is a reduction or elimination of water contaminants. One manufacturer describes the magnetic treatment processes this way: "Water and minerals are subjected to violent intramolecular vibrations and shock at the same time magnetic energy is being added, the mineral's crystallization is being upset and cohesion is being broken." Sales representatives often persuade potential customers that they can rely on magnetic treatment devices to provide lifetime, energy-free home water treatment.

The claims put forth by these devices' manufacturers and sales representatives are without validity. They do not refer to standard physical, chemical, or biological water treatment processes. Therefore, several researchers have conducted performance evaluations of the equipment and concluded that there is virtually no valid scientific data to support any water treatment benefit from magnetic devices.

WATER, WATER, EVERYWHERE?

Pennsylvania has many water resources. In an average year, about 34 trillion gallons of precipitation falls on the state. Much of this water flows through 83,000 miles of surface streams and thousands of ponds, lakes, and reservoirs. At any given moment, approximately 47 trillion gallons of water are stored beneath the surface as groundwater. It's easy to see why Pennsylvania is referred to as a "water-rich" state. As a result, we have become accustomed to adequate supplies for all uses. For most of us, water is never more than a few steps away. We only need to open a faucet, press a button, or turn a cap to quench our thirst.

WATER USE IN PENNSYLVANIA

In 1995, approximately 9,610 million gallons per day (MGD) of water were withdrawn in Pennsylvania (see Table 6.1). Over half was used to cool thermoelectric power generators. Other major water uses were for industrial and domestic activities.

The values in Table 6.1 include the total amount of water withdrawn for a particular purpose. Included in this total are both *consumptive* and *nonconsumptive* water uses. Nonconsumptive use involves the withdrawal, use, and subsequent return of the water with little or no change in quantity. Consumptive use includes activities that evaporate water. These losses are relatively small around the home (usually less than 10 percent), but nearly all of the water used for irrigation is consumptive.

Domestic water consumption has changed dramatically in Pennsylvania during the last 100 years. In 1900, only 5 million people lived in the state and each used about 5 gallons each day (25 MGD). By 1995, there were over 12 million residents, each using about 62 gallons per day (740 MGD). While long-term consumption has increased significantly, we have made progress in conserving water in the United States (see Figure 6.1). The advances made through improved water use efficiency show the potential conservation possible with continuous effort.

Water-use habits have changed dramatically since the early 1900s. Average water use by each Pennsylvanian has decreased slightly from 1985, when it was estimated to be about 65 gallons per person per day. Population shifted at that time, moving from urban centers to suburban and rural areas. These changes are adding pressure on water sources in some parts of the state while reducing use in others.

Sufficient quantities of high-quality water require a large investment in equipment, pipes, and storage facilities. A recent report by the General Accounting Office indicates that communities could save hun-

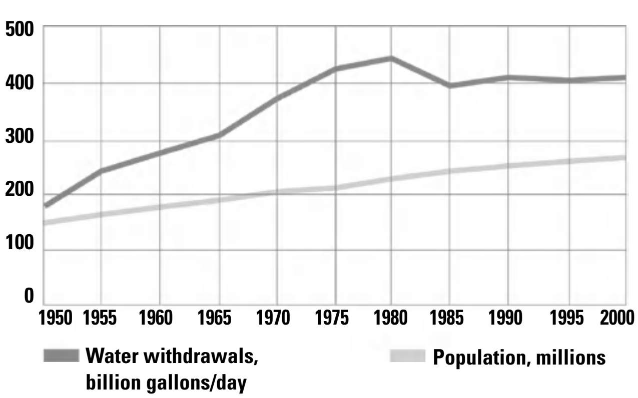
Table 6.1. Total water withdrawals and consumptive water use in Pennsylvania in 1995.

Purpose	Water use (MGD*)	Consumptive use (MGD)
Thermoelectric	5,930	239
Industrial	1,870	158
Domestic	740	74
Commercial	247	11.5
Mining	182	14
Livestock	55.3	41
Irrigation	15.9	15.9

*MGD = million gallons per day

Source: Ludlow, R. A., and W. A. Gast. 2000. Estimated water withdrawals and use in Pennsylvania. U.S. Geological Survey Fact Sheet 174-99, Washington, D.C.).

Figure 6.1. Trends in population and water withdrawals in the United States from 1950 to 2000. *(Hutson et al. 2000)*



dreds of millions of dollars on water and sewage facilities through water conservation.

Washing clothes, washing dishes, bathing, and flushing the toilet account for almost all the water consumption in homes. Water used for drinking and cooking is insignificant compared to the amount we use for waste removal. Table 6.2 details typical domestic uses.

Toilets use the most water; however, this use is much lower than it was before the advent of the low-flush (1.6 gal/flush) toilet. Washing clothes consumes the second largest amount of water.

After this water has been used, it becomes wastewater and drains to a sewer line. These lines run under the streets to sewage treatment plants. Wastewater usually flows in these pipes by gravity, and they are called gravity sewers. In older towns, storm drains are connected to this system so that rainwater also travels to the sewage treatment plant. Newer collection systems separate storm water into storm sewers and wastewater into sanitary sewers to avoid this problem.

At the sewage treatment plant, the wastewater is treated. This process includes removing nutrients and is quite costly.

On-lot disposal systems are also widely used. The first part, the septic tank, is a concrete tank into which flow wastes from an individual home. In it, solids settle to the bottom and bacteria begin to break down organic matter. The overflow is piped to an underground drainage field where organisms complete the breakdown of the sewage. Unfortunately, on-lot systems only work well in soils that can accept the effluent at an adequate rate. The less wastewater moving through this system, the better it works.

Table 6.2. Average domestic water use in the United States.

Plumbing fixture or appliance	Use (gal per person per day)
Toilet	18.5
Clothes washer	15.0
Shower	11.6
Faucets	10.9
Leaks	9.5
Other	1.6
Bath	1.2
Dishwasher	1.0
Total	69.3

Source: Adapted from Mayer et al. Residential end uses of water. 1999. American Water Works Association Research Foundation.

OUTDOOR WATER USE

Outdoor water use in the United States averages about 32 gallons per person per day. This value varies considerably in different regions. In western states, where precipitation is low, outside consumption may exceed 100 gallons per person per day. In eastern states, like Pennsylvania, outdoor water use is much lower—generally less than 10 gallons per person per day—because natural precipitation is more abundant.

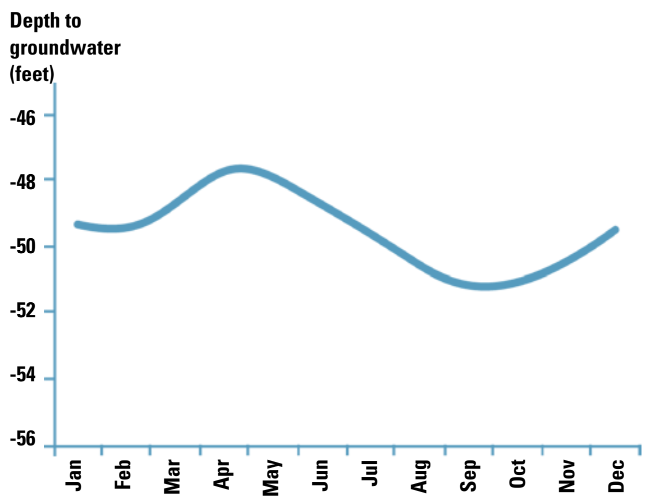
MANAGING YOUR WELL DURING A DROUGHT

In recent years, frequent droughts have caused severe water shortages in parts of Pennsylvania. Droughts can be especially stressful for the one million rural homeowners who rely on private wells for their water supply. These individual wells tap groundwater aquifers that cannot easily be seen or monitored. The invisible nature of groundwater leads to an uneasy feeling among homeowners relying on wells that their water supply could dry up without warning during a drought. This section explains the typical variation of water in wells and gives some hints for estimating groundwater levels near your well and managing your water during drought.

The Normal Cycle of Groundwater Levels

The water level in a groundwater well fluctuates naturally during the year (Figure 6.2). Groundwater levels tend to be highest during March and April in response to winter snowmelt and spring rainfall. The movement of rain and snowmelt into groundwater is known as "recharge." Groundwater levels usually begin to fall in May and continue to decline during the summer.

Figure 6.2. Natural groundwater fluctuation during the year in a typical Pennsylvania water well. *(Swistock and Sharpe, 2005)*



Groundwater recharge is limited during late spring and summer because trees and other plants use the available water to grow. Natural groundwater levels usually reach their lowest point in late September or October. In late fall, after trees and plants have stopped growing and before snow begins to fall, groundwater levels may rise in response to rainfall and recharge. Groundwater recharge persists through the fall until cold temperatures produce snowfall and frozen soil that limit water's ability to infiltrate the ground. Groundwater levels during winter may be stable or fall slightly until spring snowmelt and rainstorms start the annual cycle again. Given this natural cycle of groundwater, most problems with wells tend to occur in late summer or early fall when groundwater levels naturally reach their lowest levels.

The natural fluctuation of groundwater levels illustrated in Figure 6.2 tends to be most pronounced in shallow wells. As a result, shallow wells are usually more susceptible to drought than deeper wells. Shallow, hand-dug wells, for example, are often the first to dry up during drought. Although deeper wells may be slower to suffer from drought conditions, they may also take longer to recover after a drought has occurred.

Can Land-Use Changes Affect My Well's Susceptibility to Drought?

Dramatic changes have been made to the landscape in many rural areas of Pennsylvania. Increasing development and rural population growth will likely continue in the future. Existing rural residents often worry that these changes may create competition for groundwater and might increase their well's susceptibility to drought. It is unlikely that small numbers of new homes will cause significant changes in groundwater levels. However, more dramatic land-use changes that tap large amounts of groundwater or prevent recharge from occurring over a wide area could make existing wells more susceptible to drought. This is especially true in areas where mining is occurring or where large paved areas prevent rainfall and snowmelt from recharging groundwater.

How Can I Monitor Groundwater Levels?

Direct determination of the groundwater level in your well is difficult and usually requires using a water level meter. These meters are comprised of an electrical probe attached to the end of a measuring tape. The probe is lowered into the well until a display or light indicates that it has reached water. The depth to water is then read directly from the measuring tape. These instruments generally cost $300 or more depending on the anticipated length of tape needed.

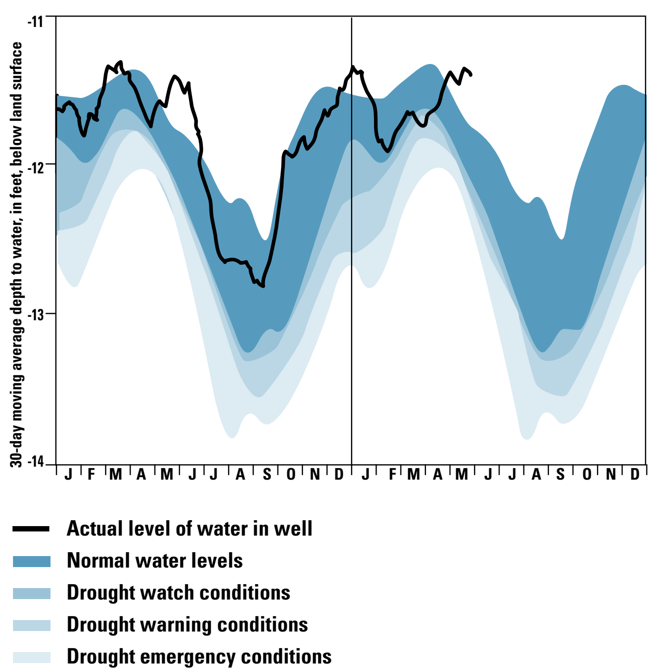
There are other less direct but more practical methods for determining the status of your well water supply. In recent years, the U.S. Geological Survey (USGS) has developed a Web-based system to access water levels from a group of monitoring wells in Pennsylvania. The USGS presently measures wells in every county. It has developed a Web page that allows viewers to access current and historic water levels in each of their monitoring wells. An example from the Adams County monitoring well is shown in Figure 6.3. This information, although not specific to your well, will allow you to observe the general trend in groundwater levels for your area. A list of the available monitoring wells by county is available at pa.water.usgs.gov.

Once you access this page, go to "Pennsylvania Current Streamflow and Ground-Water Depth Duration Graphs." Choose the well nearest to your house and select the "30-Day Graphs" to view up-to-date groundwater conditions in your area.

You can also view current groundwater levels and data for the past seven days for each monitoring well by selecting "current conditions" from the Web site listed above.

Finally, you may be able to learn more about your local groundwater conditions by contacting local well drillers and neighbors. Well drillers are continually drilling new wells and, therefore, may have knowledge of groundwater levels near your well. They may also have installed new submersible pumps in nearby wells that allow them to document the existing groundwater level. Similar discussions with neighbors who have had new pumps installed or had new wells drilled may provide valuable information about the groundwater level.

Figure 6.3. A sample graph of groundwater levels in the Adams County USGS monitoring well during 2000 and 2001. *(U.S. Geological Survey)*



How Can I Conserve Water?

Water conservation measures become critical during times of drought. Homeowners relying on private wells should begin to conserve water as soon as drought conditions occur. Water use within the home can be significantly reduced by changing habits and by installing water-saving devices.

In emergency situations, changes in water-use habits can provide quick reductions in water use. Examples might include flushing the toilet less often, taking shorter showers, only washing full loads of dishes or laundry, and collecting water from roof gutters for outside use. It is also important to note that certain drought declarations may require water-use reductions or restrictions on water use. For example, a "drought emergency" declaration bans the nonessential use of water such as for car washing and lawn watering. These regulations apply to everyone, including homeowners with private wells. For more information on ways to save water around the home, refer to "Water Conservation for the Homeowner" later in this chapter.

What Can I Do If My Well Runs Dry?

There are a number of reasons why a well may quit producing water. The most frequent cause is a malfunctioning or worn-out submersible pump. Other electrical problems such as a malfunctioning electrical switch at the pressure tank may also cause a loss of water. Pressure tanks also need to be replaced from time to time. Water-quality problems like iron bacteria and sediment may also clog the well and severely restrict water flow from the well. A professional well contractor or competent plumber should be consulted to determine the exact cause of the problem.

Under persistent dry weather conditions, the water level in your well may drop below the submersible pump, causing a loss of water. In some cases, the water level may only temporarily drop to the pump intake when water is being frequently pumped from the well during showers or laundry. Under these conditions, you may be able to continue using the well by initiating emergency water conservation measures and using water only for essential purposes.

If the water level permanently drops below the submersible pump, it may be possible to lower the submersible pump within the existing well. Usually this only provides a short-term solution to the problem. More permanent solutions require either deepening the existing well or drilling a new well. Be aware that deepening an existing well may not increase the well yield and could produce water of different quality characteristics. You should consult a local well driller or professional hydrogeologist to determine the best solution for your situation.

Proper management of private wells during droughts will become more important as competition for water in rural areas of Pennsylvania increases. By monitoring nearby groundwater levels online you may be able to detect potential problems early and implement water conservation strategies that may prevent your well from going dry.

DEALING WITH A LOW-YIELDING WELL

What Is Well Yield?

Private wells are frequently drilled in rural areas to supply water to individual homes or farms. The maximum rate in gallons per minute (gpm) that a well can be pumped without lowering the water level in the borehole below the pump intake is called the *well yield*. Low-yielding wells are generally considered wells that cannot meet the peak water demand for the home or farm. The information below describes several steps that can be used to increase the adequacy of a low-yielding well.

Peak Demand

Dealing with low-yielding wells requires an understanding of *peak demand*. A well that yields only 1 gpm of water can still produce 1,440 gallons of water in a day. However, water use in a home or farm does not occur evenly during the day. There are peak usage times, typically during the morning and/or evening, when water demand is very high. These *peak demand* periods usually last from 30 minutes to 2 hours. An adequate water system must yield enough water to satisfy a peak demand for at least 2 hours.

Let's look at an example of how a low-yielding well can fail to meet peak demand. A family of four lives in a home with a well that yields about 1 gpm. On a typical Saturday morning, there may be a 2-hour peak demand period where water is used for multiple loads of laundry, breakfast dishes, showers, toilets, and sinks. Without water-saving appliances and fixtures, the water use during this 2-hour period could exceed 300 gallons. A 1-gpm well could only provide 120 gallons of water during this peak demand period, far short of what is needed.

Ideally, peak demand is determined for the home or farm before the well is drilled. That way the well and water system can be designed to meet the peak demand. For more information on estimating your water needs, refer to Chapter 2.

So what can be done if an existing well is not meeting peak water demand? The options generally fall into two categories: reducing peak water use or increasing storage within the water system.

1. Reducing Peak Water Use

Peak water demands on the well can be reduced by changing the timing of water-using activities or by reducing the amount of water used. Examples of changing the timing of water use include spreading laundry loads throughout the week instead of doing all loads in one day, and having some family members shower at night rather than all showering in the morning.

Reducing the amount of water used involves conserving water. This might include changes in water-use behaviors such as taking shorter showers or not washing the car. Changing water-use behavior to spread out peak water use may be inconvenient at times, but there is no added cost. A more permanent but costly water conservation solution is to install water-saving devices like front-loading clothes washers or low-flush toilets. Using a front-loading washer alone saves more than 20 gallons of water for each load of laundry.

Research has shown that installing water-saving devices and appliances can reduce household water use by up to 30 percent and save hundreds of dollars per year in energy used for heating water. Examples of typical water savings from various appliances and fixtures are given in the next section. The initial cost to retrofit the home with all of these water-saving devices could conservatively cost between $1,500 and $2,000.

2. Increasing Water Storage

Inadequacies in the well water yield can also be compensated for by increasing the amount of water stored within the water system. Added storage can be achieved in a pressure tank, a large storage tank (intermediate storage), or in the drilled borehole.

Pressure Tank Storage

The pressure tank allows a water system to operate automatically. It is, in a sense, a storage tank—but it has very limited storage capacity. Its primary purpose is to create and maintain pressure on the water in the pipeline.

As water from the source is pumped into the tank, the air in the space above the water is compressed. When the pressure on the water's surface reaches about 40 pounds per square inch (psi), a pressure-activated switch stops the pump. When a faucet is opened, the air pressure forces the water out of the tank through the pipeline until the pressure drops to about 20 psi. Then the pressure regulator trips the switch and starts the pump, which forces an equal amount of water back into the pressurized tank.

About 20 percent of the capacity of the pressure tank is available for use. A 42-gallon tank discharges about 8 gallons before the pump starts (an 82-gallon tank—16 gallons; a 120-gallon tank—about 24 gallons). Thus, larger pressure tanks alone provide slightly larger amounts of stored water, but the increased storage is not enough to solve problems with a low-yielding well.

Intermediate Storage

An intermediate storage system is simply a storage reservoir that is added to receive water from the well to meet peak water demand on the home or farm. A typical system is shown in Figure 6.4.

Intermediate storage systems are based on the concept that many low-yielding wells can provide a constant but limited flow 24 hours per day without appreciable drawdown. In this case, a normal well pump may cause the water level to drop to a critical point during periods of high use, and the pump will not be able to obtain the water needed to replenish the pressure tank at the rate at which it is withdrawn.

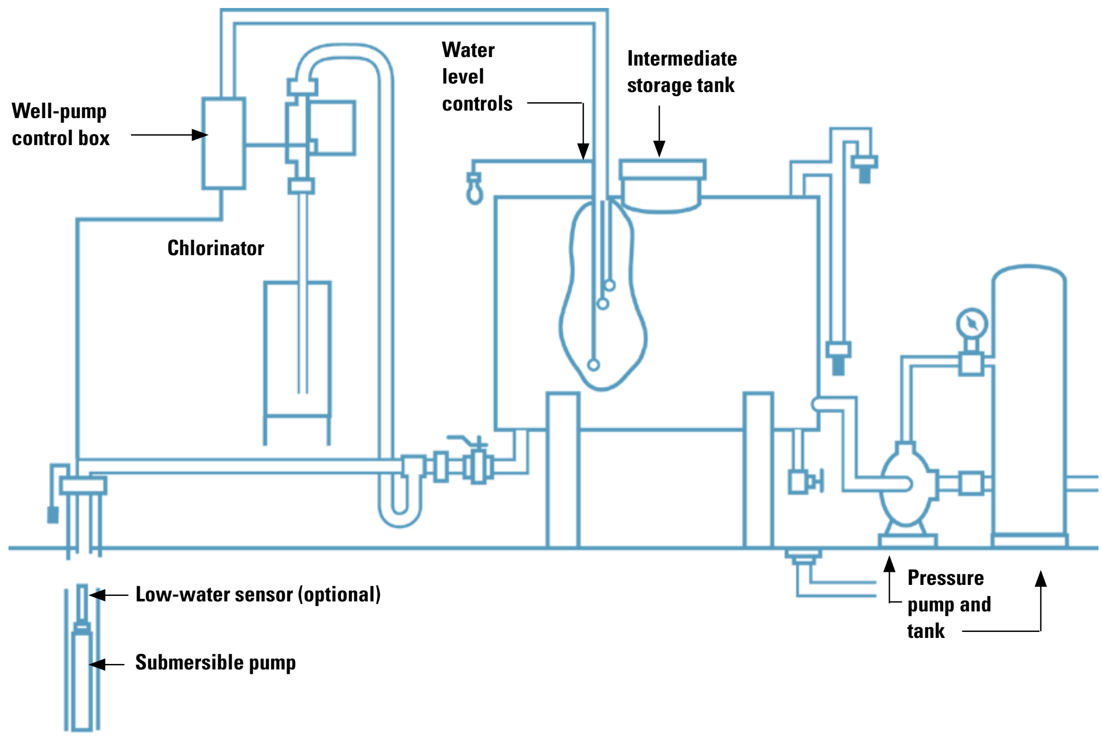
This problem can be solved by installing an intermediate storage reservoir between the well and the pressurized distribution system and limiting the pumping rate from the well. This reservoir then serves as the primary source of supply for the pressure pump. An intermediate storage water system requires two pumps and a large holding tank or reservoir at a rate that is compatible with the well's yield. The pump in the well pumps water into the reservoir; the pressure pump transfers the water from the reservoir to the pressure tank and into the distribution system. The intermediate storage tank is a nonpressurized tank or cistern, usually installed at about the same elevation of the building in which water is to be used. The depth of water stored in the nonpressurized storage reservoir is regulated either by a float switch or by a water-level sensor that controls the well pump's on-off operation.

Storage Tank Capacity

Many types of storage tanks can be installed to provide intermediate water storage. Most are made of plastic or concrete. In some instances, it may be desirable to install two intermediate storage tanks in parallel rather than one larger single unit. This arrangement provides some flexibility in that one tank can be removed from service for cleaning and maintenance while the other keeps the water system in operation.

For home water systems, the tank(s) must be protected from freezing by either burying them below the frost line or placing them in a heated garage or basement. Storage tank capacity for a residential home should be sized based on the number of people living in the house. Ideally, the storage tank(s) will hold enough water to meet a full day's water use. The tanks can then be slowly refilled overnight from the low-yielding well. As a rule of thumb, size the tank to allow for 100 gallons of water for every person in the home. Thus a family of five would need 500 gallons of storage in one or more tanks. Additional capacity should

Figure 6.4. Typical components of an intermediate storage system.



be provided if you foresee increased water demands in the future. A 300- to 500-gallon storage tank ranges from $250 to $500.

Intermediate storage tanks for farming operations are typically much larger and are sized based on the daily use of water for the farm. At a minimum, the storage tank(s) should be large enough to satisfy 2 hours of peak water use but, ideally, the tanks should be large enough to store water for an entire day. In addition, it would be wise to plan additional water storage for emergency use, such as fire protection. If the farm water use is unknown, it can be estimated using values from the section on estimating your water needs found in Chapter 2. The U.S. Department of Agriculture recommends a capacity of at least 2,000 gallons for an intermediate storage tank. Costs for large storage tanks vary from $500 (1,000 gallons) to $1,500 (3,000 gallons). Storage tanks for farm water should also be protected from freezing unless water use tends to be continuous enough to prevent freezing.

Whether they are used for home or farm water systems, intermediate storage tanks can also serve to aid in water treatment processes. If chlorine is used to disinfect the water supply, the storage tank may increase the water-chlorine contact time needed to destroy disease-producing bacteria and reduce the amount of chlorine required. The storage also serves as a treatment tank in which dissolved iron compounds oxidized by the chlorine are precipitated out of solution and settle to the bottom. Clear water remaining in the upper part of the tank is pumped into the pressure tank and distribution system.

Pressure Pump Capacity

A pressure pump is typically added after the intermediate storage tank(s) unless the system can be gravity fed to the home or barn. The pressure pump provides water to the pressure tank for distribution in the home or farm. Pressure pump capacity can be determined by estimating the total daily water requirement from the well (refer to the section on estimating your water needs in Chapter 2). Since most water is needed during a 2-hour period, the total daily water use should be divided by 2 hours and then by 60 minutes per hour to get the pump capacity in gallons per minute. For example, a single family home requiring 250 gallons of water per day (gpd) would need a pressure pump capacity of:

250 gpd / 2 hr / 60 min = 2.1 gpm

A farm well requiring 5,000 gpd would require a larger pressure pump capable of moving 42 gpm.

Well Pump Capacity

The well pump for an intermediate storage water system should have a rated pumping capacity slightly less than the yield of the well, or else a flow restrictor should be used. The pump should be expected to operate more or less continuously, if necessary, to keep the storage reservoir full. Normally, a low-water cut-off switch controlled by water-level sensors in the well should be connected to a relay at the pump switch box. A low-water signal relayed to the main switch should override other pump controls and stop the pump if the water level drops to a critically low point where air or sediment would be pulled into the system.

A schematic arrangement for an entire intermediate water-storage system is shown in Figure 6.4. Note that this diagram includes a chlorinator between the well and the nonpressurized storage tank and water level sensors in the tank. A sensing device for a low-level water cut-off switch in the well should be installed to protect the well pump. The typical cost for a household intermediate storage system (without the chlorinator) would probably be less than $1,500, depending on the amount of labor. A larger farm intermediate storage system would be closer to $3,000, but it may be significantly more if very large amounts of water must be stored.

Borehole Storage

A final method for making better use of a low-yielding well is to increase the storage of water within the borehole. The borehole may be able to store several hundred gallons of water to meet peak water demand. Ideally, extra borehole storage is added to a low-yielding well when it is first drilled to meet the expected home or farm water demand (refer to the section on estimating your water needs in Chapter 2).

The amount of water stored in a well can be increased by widening or deepening the borehole. For example, a typical 6-inch-diameter well with 100 feet of water in the borehole stores 147 gallons of water. If the 6-inch well were replaced with a 10-inch-diameter well, the storage would increase dramatically to 408 gallons of water. The additional 261 gallons of stored water may be sufficient to serve a single family home even if the well yield is very low.

Increasing diameter alone should not change the water-quality conditions from the well since it still draws water from the same aquifer. However, increasing diameter alone is risky because its success depends on a relatively constant depth of water in the well. In reality, the depth of water in the well may vary dramatically during wet and dry periods, causing the change in storage to also vary considerably. For example, a well that typically has 100 feet of water may have less than 20 feet of water storage during a drought. As a result, increasing the diameter of this well from 6 inches to 10 inches would only increase the water storage by about 50 gallons during a drought—far less than would be needed to meet peak water demand.

In wells where the water level changes significantly during dry periods, deepening the well may be a better alternative to increase borehole storage. Drilling an existing 6-inch-diameter well 100 feet deeper would increase the water storage by 147 gallons. However, there can be significant changes in water quality as you deepen an existing well. The deeper well may access groundwater with natural or human-made pollutants that may require the addition of water-treatment equipment. Consulting a local, experienced well driller and nearby well owners can be helpful in determining the risk of drilling an existing well into deeper groundwater.

Cost is an obvious consideration when increasing the diameter or depth of an existing well. Well components like the pump, wiring, conduit, and casing need to be removed before the existing well can be redrilled. Further costs are based on a per-foot drilling cost from the contractor. Some drillers may prefer simply to drill a new well to the new specifications rather than alter the existing well.

A Final Word

A low-yielding well does not have to be a source of persistent concern for a homeowner or farmer. The methods described in this guide can often be used to make these wells meet peak water demands. Simple changes in water-use habits may be enough to meet peak water demands where water shortages occur infrequently. If larger water savings are needed, water-saving devices and appliances offer large water savings and easy installation for moderate costs. More serious cases, where water availability routinely fails to meet peak water demand, warrant installation of an intermediate storage system. A local water well contractor can provide guidance and a cost estimate to increase borehole storage.

WATER CONSERVATION FOR THE HOMEOWNER

Keeping an adequate supply of high-quality water flowing from taps and disposing of wastewater requires considerable effort and expense. The less we use, the less effort and expense is required to supply us with water. The smaller the volume of wastewater produced, the less it costs to treat it. Where sewage treatment plants are already overloaded, this reduction would lessen pollution by improving waste treatment. Less energy use also means reduced air pollution and lower water-heating bills. With today's high costs for water, sewer service, and energy, conservation through efficient plumbing fixtures and appliances can result in significant homeowner savings.

Water-Efficient Plumbing Fixtures

Gravity-Flush Toilets

Water-efficient toilets have evolved over the past 30 years, with much of the pioneering work occurring in the early 1970s. Many innovations have been introduced, including toilets with two flush volumes (one for liquid and one for solid wastes) and models that incorporate water pressure in the service line to flush. The ultra-lowflush models of today retain the basic design of the gravity-flush toilet. They look like conventional models but use 1.6 gallons of water per flush versus the 3–5 gallons of older models.

These low-flush toilets are required in new construction. Congress recently commissioned a review of low-flush toilets by the General Accounting Office (GAO) in response to efforts by some officials to repeal federal requirements. The GAO report concluded that homes with these toilets used 40 percent less water for flushing, and requirements for these and other water-efficient fixtures were "effective in saving water." This unbiased, nonpartisan review firmly established this toilet's place in conserving water resources.

Replacing conventional 4-gallon-per-flush (gpf) toilets with 1.6 gpf toilets throughout your home will save approximately 12 gallons of water per day per person, which translates into over 4,000 gallons each year (see Table 6.3).

Air-Assisted Toilets

Photo courtesy of Microphor Corporation, Willits, California.

Air-assisted toilets, which require compressed air for waste removal, have been used for many years where minimal water use or waste flow reduction is at a premium. Highway rest-stop facilities are a prime example. Use of these toilets in homes is less widespread because of the need for air lines, a compressor, and the higher initial costs of air-assisted units. However, domestic use of air-assisted toilets at present water and sewer rates can be cost effective. Increased education and marketing efforts may result in wider adoption of these highly efficient toilets.

Water use per flush is only 0.5 gallons, roughly one-third the volume of low-flush toilets. With proper maintenance, air-assisted models remain serviceable for many years and more than return their significantly higher costs.

Table 6.3. Estimated water and energy savings from various water-saving fixtures.

	Frequency of use (per person)	Daily water use without water conservation device (gal/ person)*	Daily water use with water-saving devices (gal/ person)	Daily water savings with water-saving devices (gal/ person)	Annual water savings (gal/ perso)	Estimated annual energy savings of kilowatt-hours (per person)
Low-flush toilet (1.6 gpf)	5.1 flushes/day	20.4	8.2	12.2	4,453	0
Low-volume showerhead (2.5 gpm)	5.3 minutes/day	15.9	13.3	2.6	949	123
Low-volume faucet (rated flow 1.5 gpm)	4 minutes/day	12	6	6	2,190	125
Front-loading washing machine (27/gpl)	0.37 loads/day	18.9	10	8.9	3,249	316
Water-efficient dishwasher (7.0 gpl)	0.1 loads/day	1.1	0.7	0.4	146	36
Total		68.3	38.2	30.1	10,987	600

*Assumes conventional toilets at 4 gpf, showerheads at 3 gpm, faucets at 3 gpm, washing machine at 51 gpl, and dishwasher at 11 gpl.

Source: Adapted from Vickers, A. 2001. *Handbook of water use and conservation.* WaterPlow Press, Amherst, MA.

Installing air-assisted toilets is more involved, but not difficult. A small, 1/4-horsepower compressor, with an air line to each toilet, must be located in your home's garage, basement, or utility closet. Approximately 20 flushes may be made before the compressor cycles on; noise is not usually an issue. More than one toilet can be operated with the same compressor.

Composting Toilets

Interest in composting toilets has continued for several decades. These toilets use no water and rely on a mixture of human waste and other compostable organic matter. Proper maintenance is required to maintain aerobic decomposition and prevent odors.

Photo courtesy of Allen White, Bio-Sun Systems, Inc., Millerton, Pa.

Composting toilets are expensive and difficult to retrofit. They require a commitment to management and must be tended to ensure proper operation. Most on-lot sewage management jurisdictions do not relax permit requirements concerning composting toilets because the gray water portion of wastewater must be accommodated by a conventional treatment system. However, in the right situation, they may be valuable residential water-conservation tools.

Showerheads

Conventional showerheads typically deliver 3–8 gallons of water per minute (gpm). Conservation is accomplished by restricting water's flow rate through the showerhead. Showerheads with reduced flows as low as 2 gpm, at normal household water pressure, have been designed to give an acceptable shower and reduce water use. They can be sensitive to low water pressure and sudden changes in temperature; consequently, proper pressure-balanced mixing valves are necessary. Exiting water temperatures normally need to be slightly higher because the smaller droplets cool quickly. Slightly hotter water does not negate the substantial energy savings achieved by low-flow showerheads. Replacing conventional 3 gpm showerheads with the low-volume, 2.5 gpm models would save approximately 1,000 gallons of water per year per person in your home (Table 6.3).

Faucets

Most faucets deliver 3–7 gallons of water per minute. As is true of showerheads, restricting a faucet's flow rate can save water. Where faucets are operated continuously, as in washing operations, significant savings are possible. Residential, low-volume faucets typically produce 1.5–2.5 gpm. In institutional settings, flow-restricted faucets with spray heads that turn off automatically are increasingly used. When combined with point-of-use water heating, significant energy savings are possible in addition to reduced water use. Maintenance is required to prevent water loss from malfunctioning units. Replacing typical 3 gpm faucets with 1.5 gpm models would save approximately 2,000 gallons of water per year per person in your home.

Automatic Clothes Washers

Conventional, top-loading clothes washers use about 40–50 gallons of water per load (gpl). Great strides have recently been made to improve the reliability and ease of front-loading automatic clothes washers, which use less water and energy. Durability was previously an issue, especially with regard to significantly increased costs. However, newer models have resolved this issue. Front loaders are more efficient and wash with much less water and detergent. The tumbling action of the laundry reduces water requirements for equivalent load sizes and cleanliness. Possible savings are shown in Table 6.3. The reduction in hot water use saves significant energy.

Automatic Dishwashers

Automatic dishwashers have relieved us of this unpleasant mealtime chore, but they use large amounts of water. If dishwashers are fully loaded for each use, water can be saved. Newer, more efficient models may use as little as 4.5 gpl. However, units that are competitively priced use 6–7 gpl. Automatic dishwashers save water, as well as energy, by limiting hot water use. Potential savings are shown in Table 6.3. Water and energy savings quickly repay the higher cost of these machines.

Saving Money

Reducing domestic, indoor water use saves money in two ways. Homes using public supplies typically pay for each gallon delivered to them. The average cost for this water is about $5 for each 1,000 gallons, or about half a penny per gallon. As illustrated in Table 6.3, installing water-saving devices can save about 11,000 gallons of water per person per year, which translates into about $220 per year for a family of four.

Devices that reduce hot water use (such as efficient clothes washers, dishwashers, faucets, and showerheads) also save money because they consume less energy. These savings, in kilowatt-hours per person, are shown in Table 6.3. Installing these appliances could save about 600 kilowatt-hours of electricity per person annually in your home. Assuming an average energy cost of about $0.08 per kilowatt hour, this conservation translates into about $200 per year for a family of four!

Outdoor Water Conservation

Although outdoor water use is small compared to indoor uses in Pennsylvania, opportunities to save water still exist, especially during periods of dry weather when they may be most critical. Outdoor conservation is especially important since a much larger percentage of water is lost through evaporation.

Since most water outside is used to water plants, landscaping with drought-tolerant (called xeriscaping) and native plants can greatly reduce consumption. Studies in the western United States have found that residential, xeriscaped lawns use half as much water as traditional landscapes. Using mulch around outdoor plants also helps to trap moisture and reduce watering. Efficient drip irrigation systems, rather than conventional sprinklers, can produce water savings of 25–75 percent. Proper irrigation scheduling can reduce water used on lawns. This outdoor watering should be done only in the early morning (before 8 a.m.) or in the evening after sunset to minimize loss from evaporation. Ten to fifteen minutes of watering is usually enough to saturate most soils.

Rainwater harvesting, or using rain barrels, is a simple way to conserve water outdoors. Rainwater harvesting can be accomplished by placing a plastic container (such as a heavy-duty garbage can) under a downspout to collect water running off the roof. The rain collection container should be tightly covered to prevent mosquitoes from laying eggs and small animals from being trapped inside.

Summary—Why Conserve?

Installing water-efficient plumbing fixtures and appliances contributes to conserving water and energy and reducing wastewater flows. Where on-lot (septic tank) sewage disposal systems are used, reduced water use improves treatment efficiency and reduces the possibility that the system will fail. Benefits include reduced utility bills for homeowners; deferred capital expenditures for system expansions for the utilities providing water, energy, and sewer services; and a cleaner, higher-quality environment for all.

Appendix A—Relevant Web Sites and Contact Information

American Ground Water Trust:
www.agwt.org/index.htm

National Ground Water Association: www.ngwa.org/

National Ground Water Association (well owner Website): www.wellowner.org

Pennsylvania Department of Environmental Protection Private Well Homepage:
www.depweb.state.pa.us (keyword: private wells)

Pennsylvania Department of Environmental Protection regional offices:

Northeast office: **570-826-2511**

Southeast office: **484-250-5900**

Northcentral office: **570-327-3636**

Southcentral office: **717-705-4741**

Northwest office: **814-332-6945**

Southwest office: **412-442-4000**

Pennsylvania Ground Water Association:
www.pgwa.org/

Pennsylvania Ground Water Online (Department of Conservation and Natural Resources):
www.dcnr.state.pa.us/topogeo/ ground water/

Pennsylvania Master Well Owner Network:
mwon.cas.psu.edu/

Penn State Water Resources Extension:
water.cas.psu.edu/

Pennsylvania Geologic Survey, Department of Conservation and Natural Resources:
717-702-2073

USGS Water Resources of Pennsylvania:
pa.water.usgs.gov/

Appendix B—Glossary of Common Terms and Abbreviations

Acid mine drainage—Drainage of water from areas that have been mined for coal or other mineral ores; the water has a low pH, sometimes less than 2.0 because of its contact with sulfur-bearing minerals, and often contains metals in concentrations toxic to aquatic life.

Acidity—Total amount of acid and acid-forming substances in water; any substance that has a pH level below 7.

Action level—The level of any contaminant which, if exceeded, triggers treatment or other requirements that a public water system must follow.

Acute health effect—An immediate effect that may result from exposure to certain drinking water contaminants.

Aesthetic—Related to or dealing with the way something looks.

Alkaline—The condition of water or soil containing a sufficient amount of alkali substances to raise the pH above 7.0.

Aquifer—Saturated layer of sand, gravel, or rock that can readily transmit water.

Aquitards—Geologic formations made up of layers of either clay with tiny, poorly connected pores or nonporous rock; these formations restrict the flow of water from one aquifer to another.

Artesian well—Well water under pressure because of being drilled into a confined aquifer. (See also Flowing Artesian Well.) The water level in the well rises above the level of the aquifer.

Atmosphere—The whole mass of air surrounding the earth.

Background level—The average presence of a substance in the environment or occurring naturally.

Bacteria—Microscopic living organisms usually consisting of a single cell. Some bacteria in soil, water, or air may cause human, animal, and plant health problems.

Base flow—Water in a stream provided by groundwater seeping through stream banks and stream beds. Groundwater that discharges to surface water.

Borehole—A hole drilled into the subsurface.

Brine—Salty groundwater. Water of a sea or salt lake.

Calcium carbonate—A compound consisting of the elements calcium, carbon, and oxygen. Its chemical formula is $CaCO_3$. It is somewhat soluble in water. Spelunkers (cave explorers) like it because water can remove it to make a cave and rearrange it, making stalagmites and stalactites to look at. Boiler operators and cooks dislike it because it precipitates out of hot water, making stonelike deposits that are hard to remove.

Calcium carbonate ($CaCO_3$) equivalent—An expression of the concentration of specified constituents in water, in terms of their equivalent value to calcium carbonate. For example, the hardness in water caused by calcium, magnesium, and other ions is usually described as calcium carbonate equivalent.

Carcinogen—Any substance that produces cancer in an organism.

Central nervous system (CNS)—Portion of the nervous system consisting of the brain and spinal cord.

Chronic health effect—The possible result of exposure over many years to a drinking water contaminant at levels above its maximum contaminant level (MCL).

Cistern—A storage facility used for storing water for a home or farm. Often used to store rain water.

Coliform—A group of bacteria found in the intestines of warm-blooded animals (including humans) and in plants, soil, air, and water. Fecal coliforms are a specific class of bacteria that inhabit only the intestines of warm-blooded animals. The presence of coliform is an indication that the water is polluted and may contain disease-causing organisms.

Concentration—A measurement of the amount of a substance contained in a liter of water. Usually expressed as mg/L.

Conductivity—A measure of water's ability to carry an electric current. Related to the total dissolved solids (TDS) in the water.

Cone of depression—A cone shape in the water table where it has been lowered around a well due to pumping of the well.

Confined aquifer—A saturated layer of sand, gravel, or rock that has clay or nonporous rock above and below it.

Consumptive water use—Water that is used and then not returned to its source. Evaporation, transpiration, and bottled water are examples of consumptive use.

Contaminant—Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

Corrosive—The ability of water to remove substances by chemical or electrolytic activity over time, such as water pipes in a home.

Cryptosporidium parvum—Flagellate protozoan that is shed during its oocyst stage with the feces of people and animals. When water containing these oocysts is ingested, the protozoan causes a severe gastrointestinal disease.

Diameter—The length of a straight line through the center of a round object. The width of a circular or cylindrical object, such as the opening of a well.

Dolomite—A mineral consisting of a calcium and magnesium carbonate found in crystals and in extensive beds as a compact limestone.

Effluent—Waste material discharged into the environment.

EPA—The U.S. Environmental Protection Agency.

Evaporation—To pass off in vapor or invisible minute particles. The physical process by which a liquid is transferred into a gaseous state. The conversion of liquid water to water vapor.

Evapotranspiration—Loss of water from the soil by evaporation and transpiration from plants.

Exposure—Contact with a chemical or physical agent.

FDA—The Federal Food and Drug Administration.

Fecal coliform bacteria—Bacteria found in the intestinal tracts of animals. Their presence in water is an indicator of pollution and possible contamination by pathogens.

Filtration—A process for removing particulate matter from water by passage through porous media.

First draw—The water that immediately comes out when a faucet is first opened after having been unused for a significant period of time. This water is likely to have the highest levels of lead and copper contamination from plumbing materials.

Flowing artesian well—Well water under enough pressure to flow onto the land surface without being pumped.

Foliated—Composed of or separable into layers.

Gastroenteritis—An inflammation of the stomach and intestine resulting in diarrhea, with vomiting and cramps when irritation is excessive. When caused by an infectious agent, it is often associated with fever.

Geologic—Related to the study of the earth.

Giardia lamblia—Flagellate protozoan that is shed during its oocyst stage with the feces of people and animals. When water containing these oocysts is ingested, the protozoan causes a severe gastrointestinal disease called *giardiasis*.

GPM—Gallons per minute. A common unit used to express the flow of water over time.

Grain per gallon (gpg)—A unit of measure for hardness, equal to 17.1 mg/L.

Gram (g)—A unit of mass (weight) equivalent to one milliliter of water at 4 degrees Celsius. 1/454 of a pound.

Granular activated carbon (GAC)—Material used in water treatment devices to remove organic chemicals, radon, and other pollutants.

Groundwater—Water found below the ground surface and located below the water table. Also known as the "saturated zone" because all the soil pores and rock fractures are completely filled with water. The source of water is springs and wells.

Groundwater mining—Extracting groundwater faster than it is being recharged.

Gross alpha particle activity—The total radioactivity due to alpha particle emission, as inferred from measurements on a dry sample. Alpha particles do not penetrate solid materials.

Gross beta particle activity—The total radioactivity due to beta particle emission, as inferred from measurements on a dry sample. Beta particles penetrate solid materials and are more hazardous.

Hard water—Alkaline water containing dissolved salts that interfere with some industrial processes and prevent soap from lathering. Some textbooks define hard water as water with a hardness of more than 100 mg/L (as calcium carbonate).

Hardness—The presence of dissolved substances, chiefly calcium carbonate, in water. Noted by the greater amount of soap needed to produce lather and the deposits of calcium carbonate that form on heated surfaces, limiting their ability to transfer heat.

Heavy metals—Metallic elements with high atomic weights; e.g., mercury, chromium, cadmium, arsenic, and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Heterotrophic plate count (HPC)—A measure of the total number of bacteria in a sample. Also known as the *standard plate count* (SPC).

Hydrologic—Dealing with the properties, distribution, and circulation of water on the land surface, in the soil and underlying rock, and in the atmosphere.

Impervious—Not allowing entrance or passage. Impervious surfaces may include paved parking lots, buildings, etc., that cause precipitation to run off as surface water rather than percolate and infiltrate the ground.

Infiltrate—To pass into or through a substance, such as when water seeps into the soil.

Inorganic chemicals (IOCs)—Chemicals of mineral origin.

Limestone—A rock formed chiefly by the accumulation of organic remains of marine fauna, consisting mainly of calcium carbonate.

MCL (maximum contaminant level)—The greatest level of contaminants of certain chemicals allowed in public drinking water.

Microgram (µg)—One-millionth of a gram.

Micrograms per liter (µg/L)—One microgram of a substance dissolved in each liter of water. This unit is equal to parts per billion (ppb).

Microorganisms—Living organisms that can be seen individually only with the aid of a microscope.

Milligram (mg)—One-thousandth of a gram.

Milligrams per liter (mg/L)—A measure of concentration of a dissolved substance. A concentration of one mg/L means that one milligram of a substance is dissolved in each liter of water. For practical purposes, this unit is equal to parts per million (ppm).

Most probable number (MPN)—MPN is the *most probable number* of coliform group organisms per unit volume of sample water as determined by a statistical relationship. Expressed as the number of organisms per 100 ml of sample water.

ND—Abbreviation for "not detected." Laboratory expression for a concentration of a substance in water too small to be detected by the instrumentation used.

Nonconsumptive water use—Water that is used and then returned to its source, such as in hydroelectric power generation where water turns the turbines and then is returned to its source.

Nonpotable—Water that may contain objectionable pollution, contamination, minerals, or infective agents and considered unsafe and/or unpalatable for drinking.

Nonvolatile organic chemicals—Organic chemicals that do not escape readily into air from water. Also known as *synthetic organic chemicals* (SOCs).

National Sanitation Foundation (NSF)—Independent testing organization for water treatment equipment.

Nephelometric turbidity unit (NTU)—Unit of measure for turbidity in water.

Organics—A term used to refer to chemical compounds made from carbon molecules.

Oxidized—To combine with oxygen in order to break down organic waste or chemicals in water or sewage by bacterial and chemical means. Iron after combination with oxygen is called rust.

Parts per billion (ppb)—Parts of pollutant per billion parts of water a measurement of concentration on a weight or volume basis. This term is equivalent to micrograms per liter (µg/L).

Parts per million (ppm)—Parts of pollutant per million parts of water, a measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/L).

Pathogens—Microorganisms that can cause disease in other organisms or in humans, animals, and plants. They may be bacteria, viruses, or parasites found in sewage or runoff from animal farms or rural areas populated with domestic and/or wild animals.

Peak demand—Highest volume of water needed during a defined time period.

Pesticide—Any substance or chemical designed or formulated to kill or control weeds or animal pests.

pH (percent hydrogen)—Values range from 1 to 14. Water with a pH of 7 is neutral, below 7 is acidic, and above 7 is basic (usually alkaline). Used to express acidity or alkalinity of a solution in terms of the hydrogen concentration.

Percloroethylene (PCE)—A colorless nonflammable liquid often used as a solvent in dry cleaning and for removal of grease from metals.

Percolating—To trickle through a permeable material such as soil.

Picocurie per liter (pCi/L)—A measure of radioactivity in water, commonly used for radon. One picocurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second as measured by a Geiger counter.

POE (point of entry)—Describes the location of a device that treats water to the entire house.

Potable water—Water considered safe to drink.

POU (point of use)—Describes the location of a device that treats water at a particular tap.

Precipitation—Rain, snow, sleet, or hail.

Pressure tank—Tank that holds a volume of water under pressure to supply water to a system when the well pump is not running.

Primary drinking water standard—See Maximum Contaminant Level (MCL).

Public water system—A system for providing piped water for human consumption to the public, having at least 15 service connections or regularly providing water at least 60 days out of the year to 25 or more people per day. A public water system is either a *community water system* (town) or a *noncommunity water system* (gas station, camp, etc.).

Recharge—Water that enters the soil surface, trickles downward by gravity, and becomes groundwater.

Recommended maximum contaminant level (RMCL)—See Secondary Maximum Contaminant Level below.

Reservoir—A human-made lake where water is collected and stored in quantity for use.

Retrofit—To furnish with new parts or equipment not available when manufactured.

Secondary drinking water standard—See Secondary Maximum Contaminant Level (SMCL).

Secondary maximum contaminant level (SMCL)—Limits or standards given to pollutants that have only aesthetic effects in water. Also called *recommended maximum contaminant levels,* or RMCLs.

Seeps—A location where water contained in the ground oozes slowly to the surface and often forms a pool.

Septic system—An onsite system designed to treat and dispose of domestic sewage.

Soft water—Water having a low concentration of calcium and magnesium ions. According to U.S. Geological Survey guidelines, soft water is water having a hardness of 60 milligrams per liter or less.

Spring—A location where the water table or groundwater reaches the surface of the ground and results in a significant flow of water.

Standard plate count (SPC)—See Heterotrophic Plate Count (HPC) above.

Surface water—All water naturally open to the atmosphere, and all springs, wells, or other collectors that are directly influenced by surface water.

Synthetic organic chemicals (SOC)—Term used to describe nonvolatile organic chemicals such as most pesticides.

TNTC—Abbreviation for "too numerous to count." A measure of bacterial concentration.

Total dissolved solids (TDS)—A measure of all of the dissolved ions in water.

Transpiration—The passing of water through a vegetative plant and back to the atmosphere.

Trichloroethylene (TCE)—A nonflammable liquid often used as a solvent in dry cleaning and for removal of grease from metals.

Turbidity—The cloudy appearance of water caused by the presence of suspended and colloidal matter. Used to indicate the clarity of water.

Unconfined aquifer—A saturated layer of sand, gravel, or rock that has no aquitard above it. Also known as a water table aquifer.

USGS—The U.S. Geological Survey.

Virus—The smallest form of microorganism capable of causing disease.

Volatile organic chemicals (VOCs)—Organic chemicals that escape readily into the air from water.

Watershed—An area of land that drains downslope to the lowest point such as a river, lake, stream, or groundwater.

Water table—The upper surface of the saturated zone or groundwater.

Well—A deep hole or shaft sunk into the earth to obtain water, oil, gas, or brine.

Well decommissioning—The process of properly sealing an unused well to prevent groundwater pollution.

Well head protection—Limiting or eliminating the use of potentially contaminating substances within the watershed area for the well. The watershed area is difficult to establish exactly. Instead, a circular area is used. The area is centered around the well with a diameter proportional to the average daily volume of water extracted from the well. This diameter should be a minimum of 100 feet for a household well.

Appendix C—Important Information and References

CHAPTER 1

Groundwater Basics

Publication of this material was supported, in part, with funding from the Pennsylvania Water Resources Research Center made possible by the U.S. Geological Survey through the Water Resources Research Act of 1964.

Based on *A Quick Look at Pennsylvania Groundwater* by Joe Makuch, Department of Agricultural Engineering, The Pennsylvania State University; and Janice R. Ward, Water Resources Division, U.S. Geological Survey. The Pennsylvania State University and the U.S. Geological Survey Cooperating, 1986.

Publications for Additional Reading

Citizens' Guide to Groundwater Protection. Washington, D.C.: U.S. Environmental Protection Agency Office of Water, 1990.

The Geology of Pennsylvania's Groundwater by G. M. Fleeger. 3rd ed. Educational Series 3. Harrisburg: Pennsylvania Geological Survey, 1999.

Groundwater Protection and Management in Pennsylvania: An Introductory Guide for Citizens and Local Officials. 3rd ed. Washington, D.C.: League of Women Voters, 2001.

Pennsylvania Groundwater Quality. U.S. Geological Survey Water Supply Paper 2325, National Water Summary. Reston, Va.: U.S. Geological Survey, 1986.

Protecting Your Groundwater. Educating for Action. League of Women Voters Education Fund, Pub. No. 180. Washington, D.C.: League of Women Voters, 1994.

CHAPTER 2

Water System Planning—Estimating Water Needs

Sources of Water Use Estimates

1. *Planning Guide for Water Consumption.* 1981. Agricultural and Biological Engineering Fact Sheet SW-1. Penn State Cooperative Extension.

2. *Private Water Systems Handbook.* 1992. Midwest Plan Service. MWPS-14.

3. *Handbook of Water Use and Conservation.* 2001. Water-Plow Press. Amherst, MA.

4. *Consumptive Water Use Restrictions in the Delaware River*

Basin. 2002. Agricultural and Biological Engineering Fact Sheet F-199, Penn State Cooperative Extension.

5. *Guideline for Milking Center Wastewater.* 1998. Natural Resource, Agriculture, and Engineering Service. NRAES-115.

Dealing with Unused Wells

Well-decommissioning procedures based on the recommendations of the National Ground Water Association, www.ngwa.org

Smith, Stuart. 1998. *Manual of Water Well Construction Practices.* Westerville, Ohio: National Ground Water Association Press.

Spring Development and Protection

Images adapted from *Safeguarding Wells and Springs from Bacterial Contamination,* 1996, Department of Agricultural and Biological Engineering, The Pennsylvania State University.

Rainwater Cisterns

Contribution No. 173, "Feasibility of Rainwater Collection Systems in California" by David Jenkins and Frank Pearson. Available from California Water Resources Center, University of California, 475 Kerr Hall, Davis, California 95616.

Customer information brochure, Water Filtration Co., 108B Industry Road, Marietta, Ohio 45750.

Private Water Systems Handbook, 1979. Publication MWPS-14, Midwest Plan Service, Iowa State University, Ames, Iowa 50010, attn. Extension Agricultural Engineer.

CHAPTER 3

Sharpe, W. E., Mooney, D. W., and Adams, R. S. 1985. "An Analysis of Groundwater Quality Data Obtained from Private Individual Water Systems in Pennsylvania." *Northeastern Environmental Science,* 4(3-4), 155-59.

Swistock, B. R., Sharpe, W. E., and Robillard, P. D. 1993. "A Survey of Lead, Nitrate and Radon Contamination of Private Individual Water Systems In Pennsylvania." *Journal of Environmental Health,* 55(5), 6-12.

Swistock, B. R., S. Clemens, and W. E. Sharpe. 2009. Drinking water quality in rural Pennsylvania and the effect of management practices. Final report, The Center for Rural Pennsylvania, Harrisburg, PA, for Cooperative Agreements 2006-7 and 2007-10. Available online at www.ruralpa.org.

Roadside Dumps and Water Quality

Christensen, T. H., R. Cossu, and R. Stegmann. 1992. *Landfilling of Waste: Leachate.* New York: Elsevier Applied Science.

Closz, J., P. Gill, D. Lane, and E. Long. 1995. *Is Illegal Dumping a Problem in Huntingdon County?* Huntingdon Area School District Senior Humanities Project.

Izzo, Becky. 2002. *Project Trash: Learning about Littering and Illegal Dumping.* Greensburg: PA CleanWays.

Peavy, Howard, D. R. Rowe, and G. Tchobanoglous. 1985. *Environmental Engineering.* New York: McGraw-Hill.

Pennsylvania Bulletin, Volume 22, Number 27, July 4, 1992.

Pennsylvania Code, Title 25, Chapters 271–85. Commonwealth of Pennsylvania. Current through 32 Pa. B. 2572 (May 18, 2002).

Pennsylvania Code, Title 25, Chapters 260–70. Commonwealth of Pennsylvania. Amended through January 16, 1993.

Pennsylvania Code, Title 25, Chapters 75, 101, 271, 273, 277, 279, 281, 283, 287–89, 293, 295, 297, and 299. Commonwealth of Pennsylvania. Current through July 4, 1992.

Qasim, Syed R., and Walter Chiang. 1994. *Sanitary Landfill Leachate: Generation, Control and Treatment.* Lancaster, Pa.: Technomic.

Swistock, Bryan, W. E. Sharpe, and J. Clark. 2003. *Water Tests: What Do the Numbers Mean?* University Park, Pa.: The Pennsylvania State University.

Tammemagi, Hans. 1999. *The Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future.* New York: Oxford University Press.

Unknown. 1998. *Illegal Dumping Prevention Guidebook.* Chicago, Ill.: U.S. Environmental Protection Agency Region 5, Waste, Pesticides, and Toxics Division.

Unknown. 1998. *Safe Drinking Water Program Summary of Key Requirements for Community Water Systems.* Commonwealth of Pennsylvania, Department of Environmental Protection, Bureau of Water Supply Management.

U.S. Environmental Protection Agency. 2004. *2004 Edition of the Drinking Water Standards and Health Advisories.* Washington, D.C.: EPA Office of Water.

Westlake, Kenneth. 1995. *Landfill Waste Pollution and Control.* Chichester: Albion.

Gas Well Drilling

Clark, J., B. R. Swistock, and S. Clemens. 2007. Unpublished data collected from 200 private water wells in McKean County.

Gough, W. R., and B. A. Waite. 1990. "Oil and Gas Exploration and Water Quality Considerations," Chapter 29 in: *Water Resources in Pennsylvania: Availability, Quality and Management.* Edited by S. K. Majumdar, E. W. Miller, and R. R. Parizek. The Pennsylvania Academy of Science. pp. 384-98.

DeWalle, D. R., and and D. G. Galeone. 1990. "One-Time Dormant Season Application of Gas Well Brine on Forest Land." *Journal of Environmental Quality*, 19:288-95.

Pennsylvania Department of Environmental Protection, 2007. "Oil and Gas Well Drilling and Production in Pennsylvania." DEP Fact Sheet 2018, 3 pp.

CHAPTER 4

Swistock, B. R., S. Clemens, and W. E. Sharpe. 2009. Drinking water quality in rural Pennsylvania and the effect of management practices. Final report, The Center for Rural Pennsylvania, Harrisburg, PA, for Co-operative Agreements 2006-7 and 2007-10. Available online at www.ruralpa.org.

Zogorski, J. S., J. M. Carter, T. Ivahnenko, W. W. Lapham, M. J. Moran, B. L. Rowe, P. J. Squillace, and P. L. Toccalino. 2006. *Volatile Organic Compounds in the Nation's Ground Water and Drinking-Water Supply Wells,* USGS Circular 1292.

CHAPTER 5

Alleman, J. E. 1985. "A Performance Evaluation For Magnetic Water Treatment." Fourth Domestic Water Quality Symposium. ASAE and Water Quality Association, 16 November.

Duffy, E. A. 1977. Investigation of Magnetic Water Treatment Devices. Doctoral Thesis. Clemson University.

Gruber, C. E., and D. D. Carda. 1981. "Measurable Parameters in Water Conditioning Equipment as Determined in Laboratory Simulations at Rapid City, South Dakota." Final report issued to the Water Quality Association. South Dakota School of Mines and Technology.

Iowa Judgment on Electromagnetic Water Conditioning Device. Water Quality Association release.
Mitchell, H. 1987. "Magnetic 'Water Softener' Found to Be the Stuff of Legend, Not Fact." *The Toronto Star.* September 19.

Nowlin, D. D. 1983. Magnetic Water Treatment Facts and Fallacies. American Society of Agricultural Engineers, Winter Meetings, 1983.

Swistock, B. R., S. Clemens, and W. E. Sharpe. 2009. Drinking water quality in rural Pennsylvania and the effect of management practices. Final report, The Center for Rural Pennsylvania, Harrisburg, PA, for Co-operative Agreements 2006-7 and 2007-10. Available online at www.ruralpa.org.

CHAPTER 6

Hutson et al. 2000. *Estimated Use of Water in the United States in 2000.* U.S. Geological Survey, Circular 1268, Washington, D.C.

Swistock, B. R., and W. E. Sharpe. 2005. "Managing Your Well During A Drought." Penn State Cooperative Extension, Water Facts #7.

Water Conservation—How Much Water and Money Can You Save?

Water and energy use estimates in this fact sheet are based on information published in: Vickers, A. 2001. *Handbook of Water Use and Conservation.* WaterPlow Press, Amherst, MA.

APPENDIX B

"Arizona Know Your Water," University of Arizona, Artiola, Farrell-Poe and Moxley, 2006.

Websters Ninth New College Dictionary, Merriam-Webster, Inc., Springfield, MA. 1983.

Water Words Dictionary, Nevada Division of Water Resources, Department of Conservation and Natural Resources.

Visit Penn State's College of Agricultural Sciences on the Web: agsci.psu.edu

Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

This publication is available from the Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802. For information telephone 814-865-6713.

This publication is available in alternative media on request.

Produced by Ag Communications and Marketing

CODE # AGRS-111 1M809MPC 4954