Texas A&M AgriLife Extension

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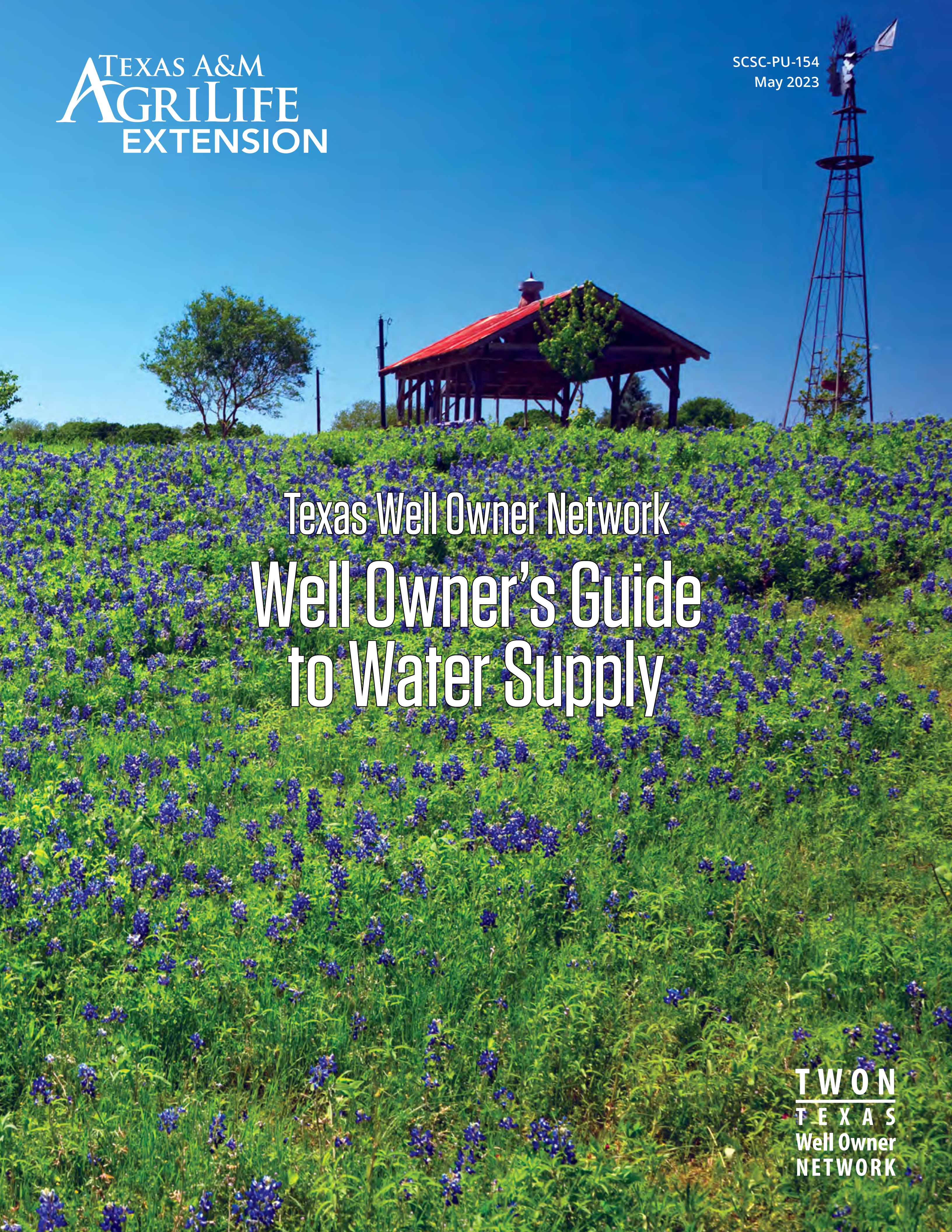
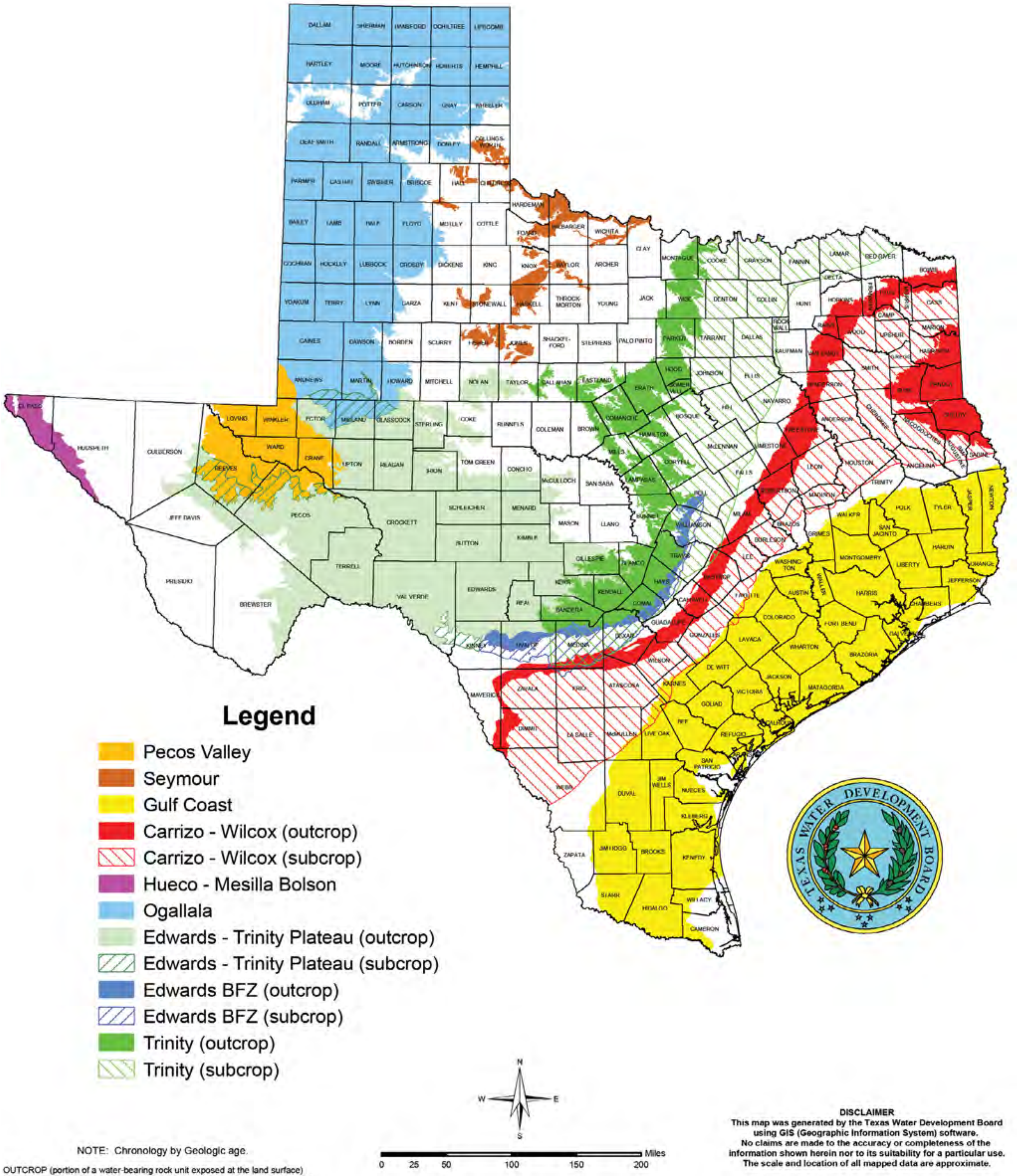


Texas Well Owner Network

Well Owner's Guide to Water Supply

TWON
TEXAS
Well Owner
NETWORK

Major aquifers of Texas.



NOTE: Chronology by Geologic age.

OUTCROP (portion of a water-bearing rock unit exposed at the land surface)
SUBCROP (portion of a water-bearing rock unit existing below other rock units)

DISCLAIMER
This map was generated by the Texas Water Development Board using GIS (Geographic Information System) software.
No claims are made to the accuracy or completeness of the information shown herein nor to its suitability for a particular use.
The scale and location of all mapped data are approximate.

Map updated December 2006 by Mark Hayes, GISP

https://www.twdb.texas.gov/mapping/index.asp

Texas Well Owner Network
Well Owner's Guide to Water Supply

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Contents

Chapter 1. Introduction

Chapter 2. Aquifers in Texas

Chapter 3. Physiographic Provinces of Texas and Aquifer Types

Chapter 4. Watersheds and Aquifers

Chapter 5. Well Siting and Construction

Chapter 6. Water Quantity

Chapter 7. Water Quality

Chapter 8. Common Contaminants in Well Water

Chapter 9. Water Quality Testing

Chapter 10. Water Treatment Options

Chapter 11: Protecting Your Well Water Quality

APPENDICES

Acknowledgments

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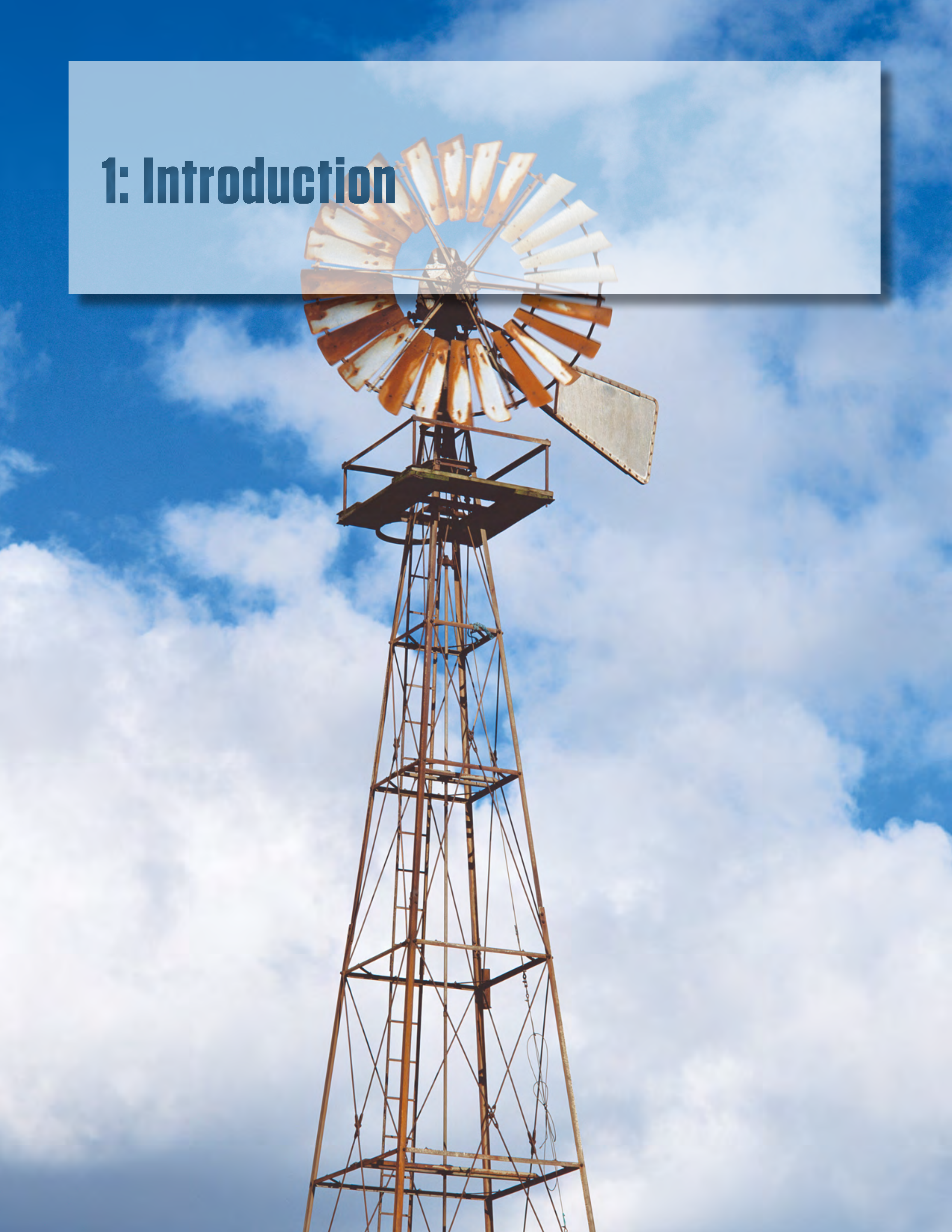
Disclaimer

1: Introduction



Household well owners in Texas are responsible for ensuring that their well water is safe to drink. People who drink polluted water can become sick and, in some cases, die. Health problems caused by contaminated well water include illnesses from bacteria such as *E. coli,* "blue baby syndrome," and arsenic poisoning.

Unsafe drinking water from wells is often caused by high concentrations of minerals—such as arsenic and uranium—that occur naturally across Texas. Well water can also be polluted by seepage from failed septic tanks and by synthetic compounds such as fertilizers, gasoline, and pesticides.

According to the Centers for Disease Control, up to 30 percent of United States (U.S.) households depend on private wells for drinking water. Of the water used in Texas, roughly 60 percent is from groundwater, which is the water below the earth's surface.

In Texas, as across the U.S., the government does not routinely test household well water to make sure it is safe to drink. The well driller may have the water tested for bacteria when the well is first installed; thereafter, it is the well owner who is responsible for making sure the water is safe.

Our water's quality and quantity are greatly affected by the way we live. If we learn about our water resources and understand how our activities affect them, we can help keep our water safe to drink as well as preserve, protect, and enhance this vital resource.

About the Handbook

This publication was created to help Texans keep their well water safe to drink and use. It was written for the participants in the Texas Well Owner Network (TWON) and Texas residents who depend on household wells for their drinking water. It provides information about Texas groundwater sources, water quality, water treatment, and well maintenance issues.

About the Texas Well Owner Network

The Texas Well Owner Network is an educational program that aims to:

- Educate residents about water issues, with a focus on groundwater
- Help Texans improve their water's quantity and quality
- Help residents implement community watershed protection plans and participate in the Texas Watershed Steward program

Anyone who wants to learn about, improve, and protect community water resources can participate in the Texas Well Owner Network. The network includes well owners, agricultural producers, decision makers, and community leaders.

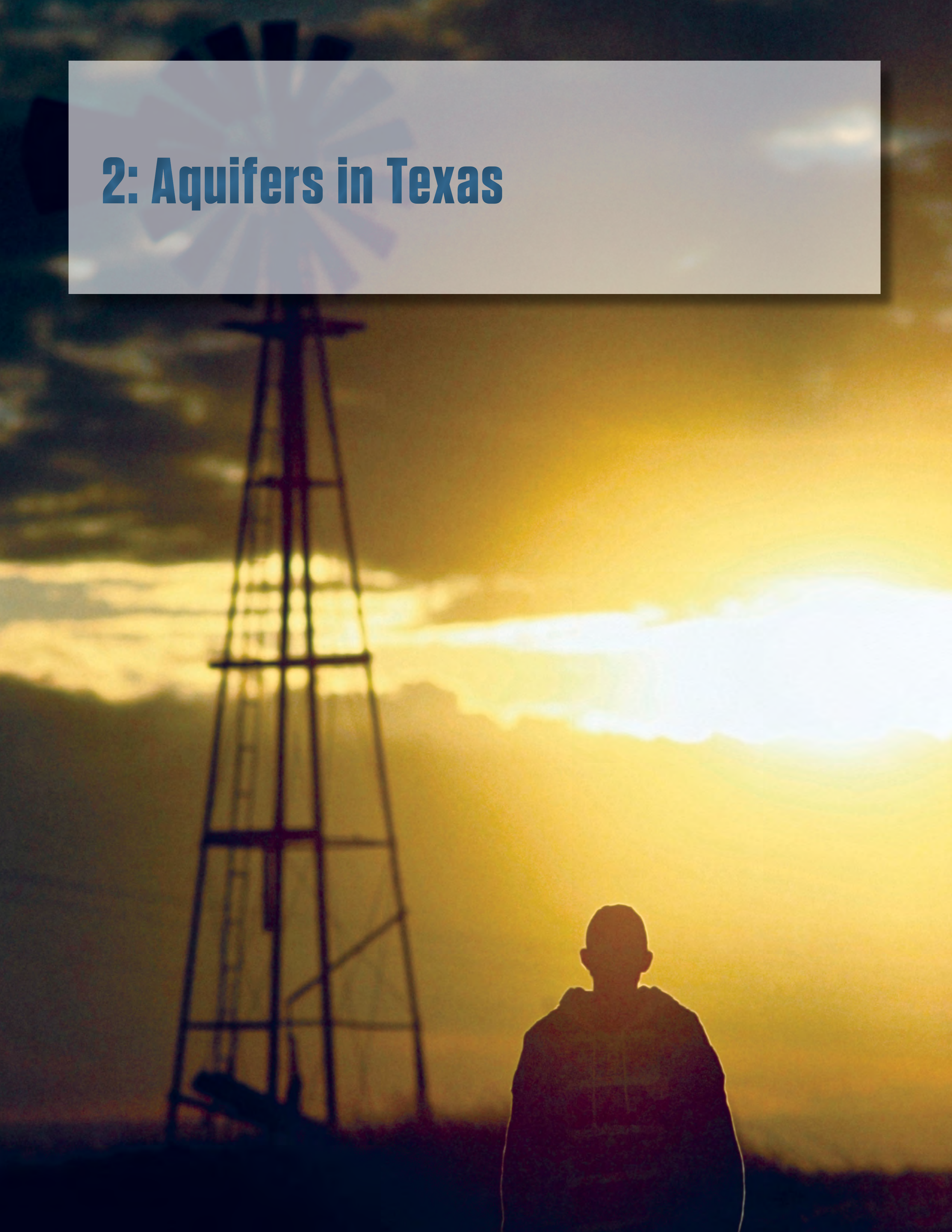
The Texas Well Owner Network is being offered by the Texas A&M AgriLife Extension Service in cooperation with the Texas State Soil and Water Conservation Board and other agencies and organizations.

References

Bartholomay, R. C., J. M. Carter, S. L. Qi, J. H. Squillace, and G. L. Rowe. 2007. *Summary of Selected U.S. Geological Survey Data on Domestic Well Water Quality for the CDC NEPHTP.* USGS Report 2007-5213.

U.S. Census Bureau. Current Housing Reports, Series H150/07, *American Housing Survey for the United States: 2007,* U.S. Government Printing Office, Washington, DC: 20401, 2008.

2: Aquifers in Texas



An aquifer is an underground geologic formation that can produce (yield or transmit) usable amounts of water to a well or spring. Aquifers may be composed of one or a combination of materials (Fig. 1):

- **Unconsolidated** (loose) rock materials include the sands and gravels of river valleys. In unconsolidated aquifers, water is held in the empty spaces (pores) between grains of clay, silt, sand, and gravel.
- **Consolidated** (bound or cemented) rock materials include the granite formations of the Hill Country of Central Texas and the limestone formations in the Edwards Aquifer. In consolidated aquifers, the water is held in the fractures and cracks of rock.

How Aquifers Develop

Knowing how an aquifer has developed geologically can help you understand how much water that a well can yield and how vulnerable it is to contamination.

Unconsolidated aquifers are formed when wind or water moves and deposits geologic materials such as sand and gravel. Materials moved by flowing water are said to be *alluvial.* Materials moved by wind are termed *aeolian.*

When sediment is moved, it is often sorted into particles of similar sizes. For example, sand grains deposited by wind that form a sand dune tend to be about the same size. Fast-moving rivers can transport gravel and large cobbles (rocks about 2½ to 10 inches in diameter); in contrast, lakes and slow streams form layers of fine silt and clay at the bottom.

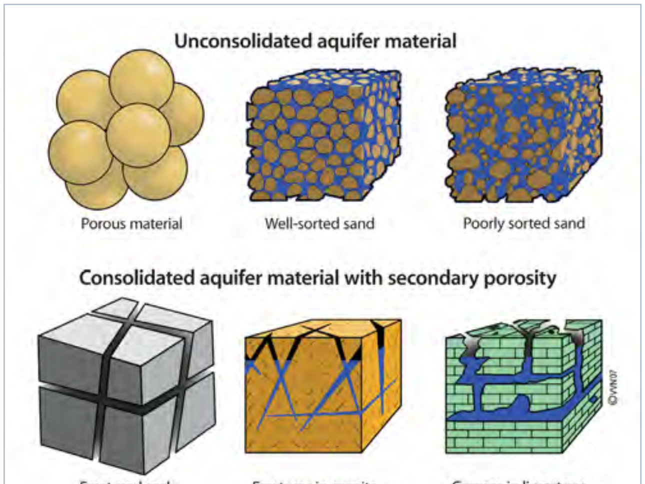


Figure 1. Aquifers can be composed of unconsolidated materials, consolidated materials, or a combination of both.

In some types of sediment movements, the materials are not sorted well, such as when landslides deposit loose and jumbled bits of rock and sediment known as *colluvium.* Aquifers formed in poorly sorted, unconsolidated materials are called *colluvial aquifers*.

Some sediments harden into consolidated rock in a process known as *lithification.* An example of lithification is when lava cools and hardens into solid basalt. Other examples are when sediments are buried and squeezed under pressure to form shale, or when they are melted and metamorphosed to form granite.

These consolidated rocks can be weathered by biological, chemical, and physical processes. Weathering produces the clay, silt, sand, gravel, and other rock fragments that compose unconsolidated aquifers.

The transition between unconsolidated to consolidated rock can be subtle, but it is generally true that if you can dig at the aquifer material with a spoon, the aquifer is unconsolidated.

Water Movement in Aquifers

In unconsolidated aquifers, water flows through the interconnected pores between grains of sediment. The ratio of space to these grains is known as *primary porosity.*

Water moves faster through an aquifer made of sand particles, which are larger (0.05 to 2 mm) than those of other types of soil and create larger pore spaces. Water flows much more slowly around silt and clay particles, which are smaller (less than 0.05 mm) and have smaller pore spaces. Small particles tend to filter water more effectively, removing many pollutants before they can reach the aquifer; the large pollutants cannot get through a fine filter.

Consolidated aquifers develop when rock breaks or fractures; the ratio between the spaces and the rock is called *secondary porosity.* In a consolidated rock aquifer, secondary porosity can be increased by breaking up, or fracturing, the rock. This process is the basis of hydraulic fracturing procedures carried out to increase gas, oil, and water well output (see Chapter 11).

What Creates an Aquifer?

As melted rock circulates deep inside the earth, it lifts, moves, and breaks up enormous plates of rock using natural influences called *tectonic forces.* These forces cause continental drift, the movement of the earth's continents in relation to each other.

Did You Know?

Today, continental shift is causing the Atlantic Ocean to expand by about 1 inch per year. Over a lifetime, this expansion will increase the distance between New York and London by about 6 feet.

In Texas, aquifers have been formed by this geologic activity in the Mississippi River Valley, the Rocky Mountains, and the Rio Grande River Valley (Fig. 2). The activity had its beginnings about 200 million years ago, when the North American continental plate began pulling away from Europe. Over time, this expansion created the Atlantic Ocean.

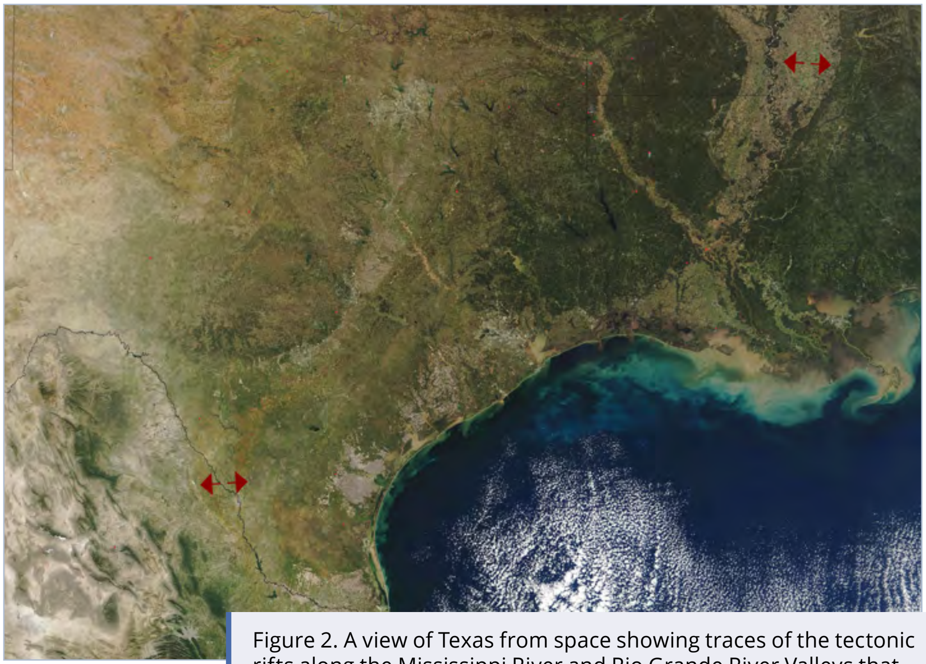


Figure 2. A view of Texas from space showing traces of the tectonic rifts along the Mississippi River and Rio Grande River Valleys that formed many aquifers across the state.

As continent-sized plates of rock pull apart and push together, they generate earthquakes, form mountains, and create chasms called *rifts.* Sediment is moved and deposited into the rift valleys and farther downstream.

Did You Know?

In 1811 and 1812, the largest earthquake recorded in the continental United States occurred in a rift near New Madrid, MO (Fig. 3). During the earthquake, parts of the Mississippi River dropped by as much as 10 feet. Several days passed before the river flow stabilized.

The coastal and eastern Texas aquifers were created by the geologic activity around the Mississippi River and the Gulf of Mexico, which formed in a rift valley more than 750 million years ago.

The Mississippi Valley continues to subside, moving sediments to form a thick delta, or alluvial fan, that extends into the Gulf of Mexico. A delta is an outspread, gently sloping landform that takes the shape of a fan. Sediment from Central Texas has also been deposited along the eastern coast of Texas, creating wedges of sediment that thicken in the direction of subsidence (Fig. 4).

Over millions of years, subsidence and changes in sea level have caused the shoreline of the Gulf of Mexico to advance and retreat. During that period, most of Texas was often covered with ocean water.

In the High Plains of Texas, erosion of the Rocky Mountains has created very thick deposits of sediment. Much of the High Plains and the central Great Plains of the United States is covered with layers of unconsolidated sediments.

In West Texas, the Rio Grande River is in a rift valley that began forming 35 million years ago as the southwest portion of the continental plate was pulled west. The Rio Grande Rift extends from southern Colorado into Mexico, and

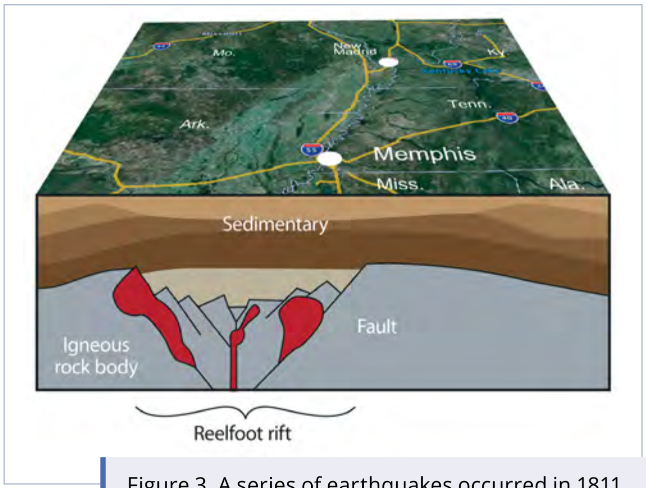


Figure 3. A series of earthquakes occurred in 1811 and 1812 along the New Madrid fault system. Some shocks were felt as far away as Toronto, Canada.

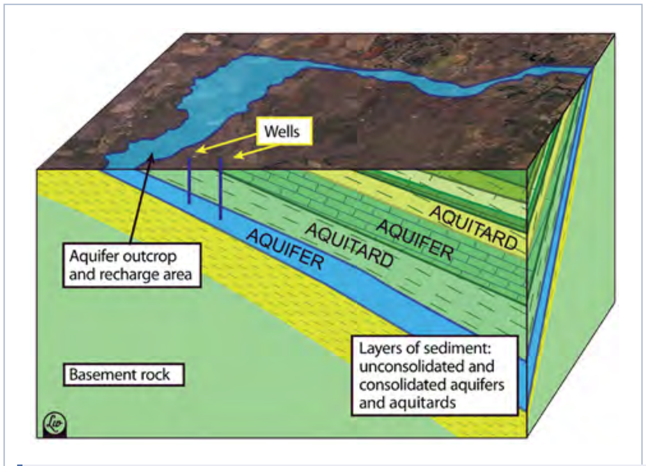


Figure 4. Alluvial sediments in eastern Texas, with deposition in the direction of the Gulf of Mexico subsidence.

the Rio Grande River follows the depression in the land surface. In contrast to the rest of Texas, the Rio Grande Valley is more arid, and there is not enough moisture to erode and transport sediment. Here, gravity moves most of the sediment (Fig. 5).

In some areas, the earth's crust is stretched and broken by faults that are nearly vertical. Large, consolidated blocks of rock are moved vertically to create mountain ranges and basins (broad valleys). The mountaintop can be as much as 10,000 feet from the valley basement. The valleys can be filled with up to 7,000 feet of gravel, sand, and silt.

This type of natural landscape feature is called a *basin and range landform.* Such landforms are prevalent across the Basin and Range Province, which is located from West Texas to California.

Volcanoes in the Basin and Range Province created igneous rock (rock made from molten or partly molten material) such as basalt. In parts of West Texas, consolidated aquifers have formed in this igneous rock.

In West, East, and South Texas, tectonic forces stretched rock that later eroded. The sediment that was deposited over millions of years eventually formed aquifers. In the Llano Uplift of Central Texas, tectonic forces brought basement rock, the deep core of the continental plate, to the land surface (Fig. 6).

Limestone consists of calcium carbonate from the skeletal remains of ocean creatures such as coral (Fig. 7). Beds of limestone were deposited in the Gulf of Mexico as the shoreline advanced and retreated over the landscape.

Although limestone is a consolidated rock, it is very soluble. When slightly acidic water moves through the fractures and cracks in limestone, the rock dissolves and karst landscapes develop.

Unconsolidated rock aquifers are formed from sediment transport and deposition; consolidated rock aquifers

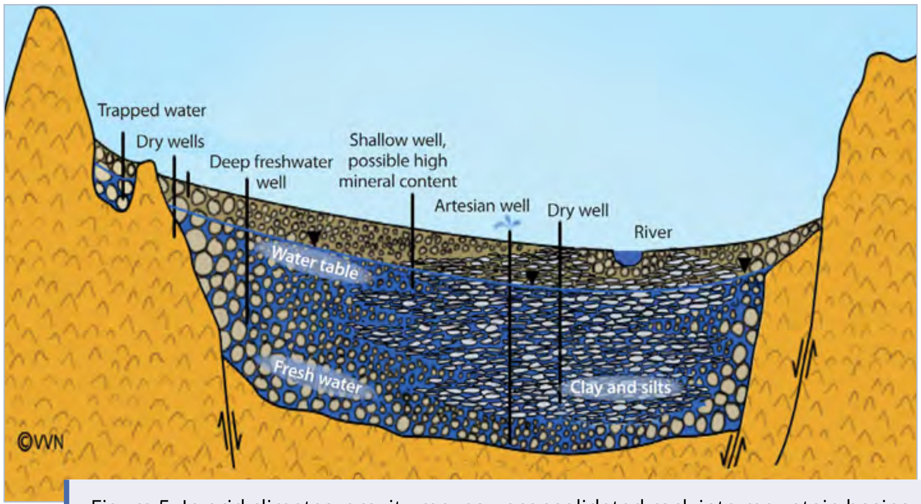


Figure 5. In arid climates, gravity moves unconsolidated rock into mountain basins.

erode and provide the source of sediment. Through time, the unconsolidated sediments may become compacted and eventually transition into consolidated rock aquifers. When the pore spaces are filled with fresh water, these aquifers become potential sources of drinking water.

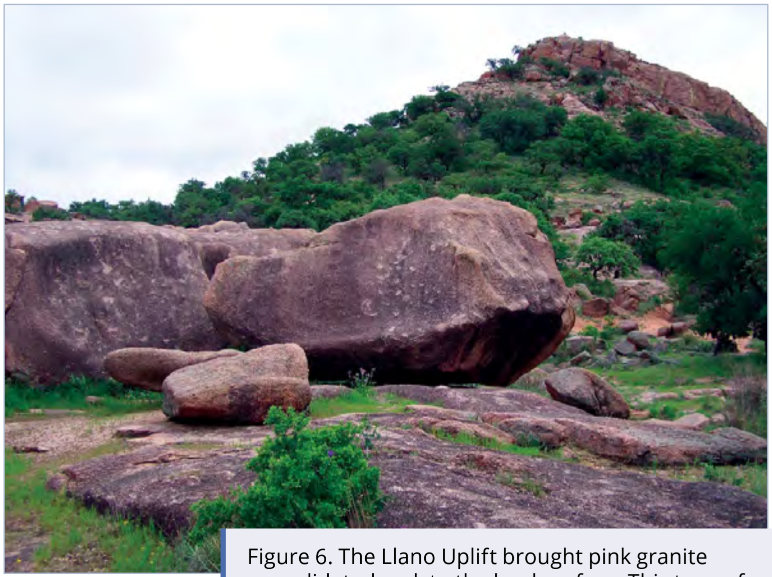


Figure 6. The Llano Uplift brought pink granite consolidated rock to the land surface. This type of granite was used to build the state capitol in Austin.

Figure 7. Canyon Lake Gorge showing Glen Rose limestone.

Aquifer Recharge

Water from rain and snowfall seeps through the soil and recharges (replenishes) the aquifer. When the aquifer is recharged, the water table elevation rises; during drought, it drops (Fig. 8). The depiction of the change in water-table elevation over time is called a hydrograph.

Only some of the rain or snow recharges the aquifer; most of the water evaporates, is taken up by plants, or drains off the landscape into streams and rivers. The amount of groundwater that an aquifer can hold is determined by its porosity.

Scientists can determine how fast and how often an aquifer is recharged by measuring isotopes (different forms of an element) of hydrogen and oxygen as well as other elements, such as carbon, that have dissolved in the water. As precipitation passes through the atmosphere, it picks up a unique isotopic fingerprint that can be used to measure how long ago the water fell as precipitation. Hydrologists can then calculate the time since the aquifer was recharged, or the age of the water.

Aquifer recharge can occur many miles from a well. For example, water can filter underground where the aquifer is exposed at land surface. The water can then be extracted miles from the recharge area.

Recharge can also occur along streams and from lakes and reservoirs, wherever water is in contact with the aquifer.

Reference

Scanlon, B. R., and A. Dutton, M. Sophocleous. (2003) *Groundwater Recharge in Texas.* Texas Water Development Board, Austin, TX.

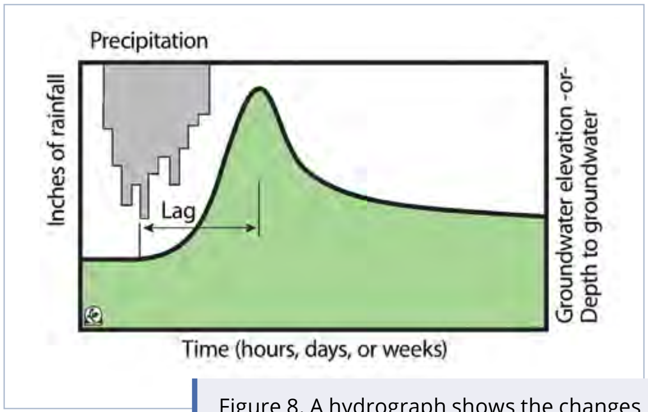
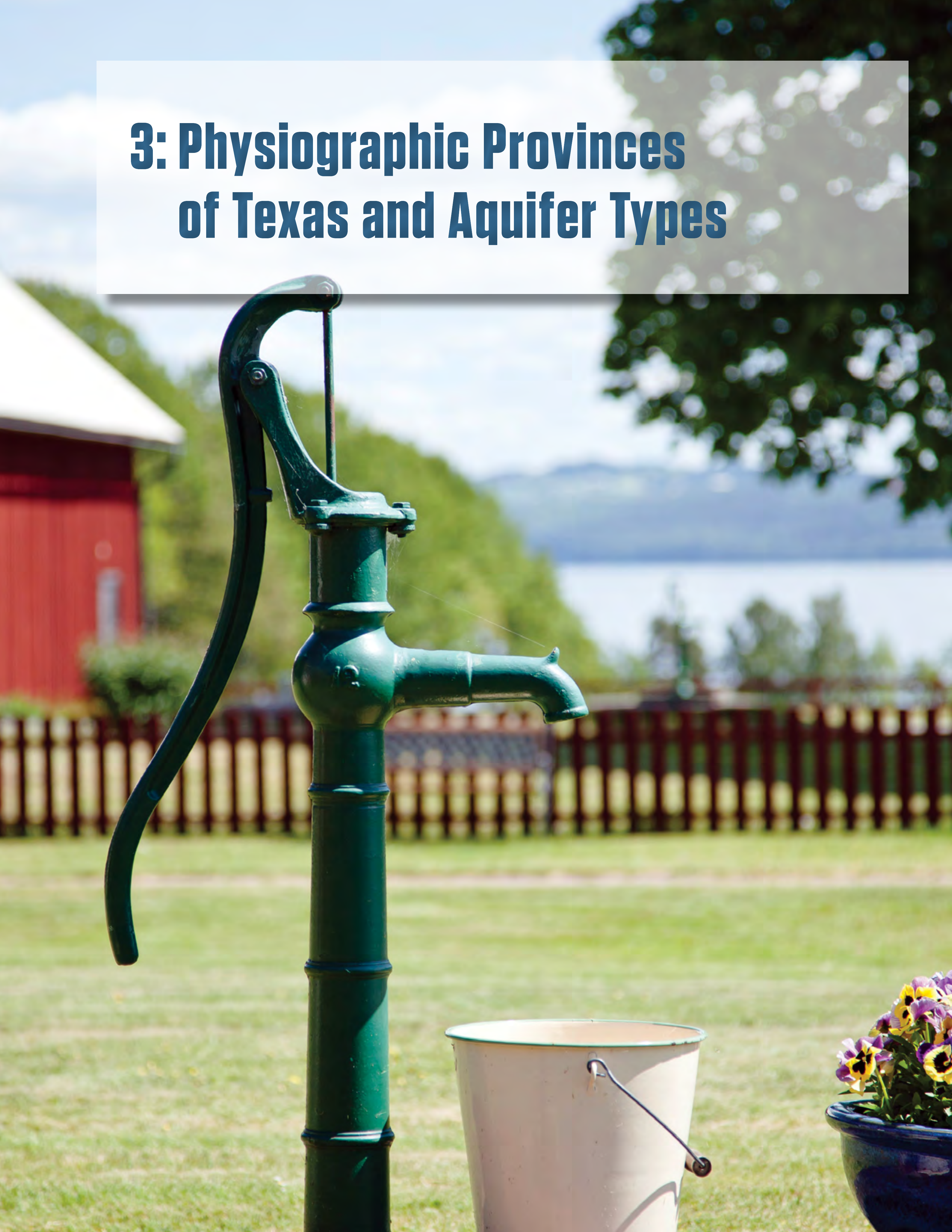


Figure 8. A hydrograph shows the changes in water-table elevation over time.

Figure 9. Flowing artesian well developed for the Port Arthur, Texas, water supply (circa 1910).

Notes

3: Physiographic Provinces of Texas and Aquifer Types



Geologic forces have formed seven physiographic provinces in Texas (Fig. 10). The landscape in each province has a similar geologic history and similar rock and soil types, vegetation, landforms, and climate. The types of aquifers and groundwater quality in each province are unique to that region.

The provinces are described below using information from the *Physiographic Map of Texas,* which was produced in 1996 by the Bureau of Economic Geology. Also listed below are the aquifer(s) in each province as well as the predominant aquifer expected to provide water for a domestic, household well.

See the inside covers of this handbook for maps of the major and minor aquifers of Texas that were developed by the Texas Water Development Board (*https://www.twdb.texas.gov/).*

High Plains

The High Plains of Texas (pink area of Fig. 10) form a nearly flat plateau with an average elevation of about 3,000 feet above sea level. The communities of Midland, Lubbock, and Amarillo are located on the High Plains (Fig. 11), and the Canadian and Pecos Rivers erode and drain the highlands.

The Ogallala aquifer underlies the High Plains and extends from Texas to South Dakota, supplying groundwater for irrigation and other uses. The Ogallala consists of unconsolidated, poorly sorted sands, gravels, and clays that erosion of the Rocky Mountains has deposited over the past 10 million years. Windblown sands and silts form rich soils that overlie the Ogallala.

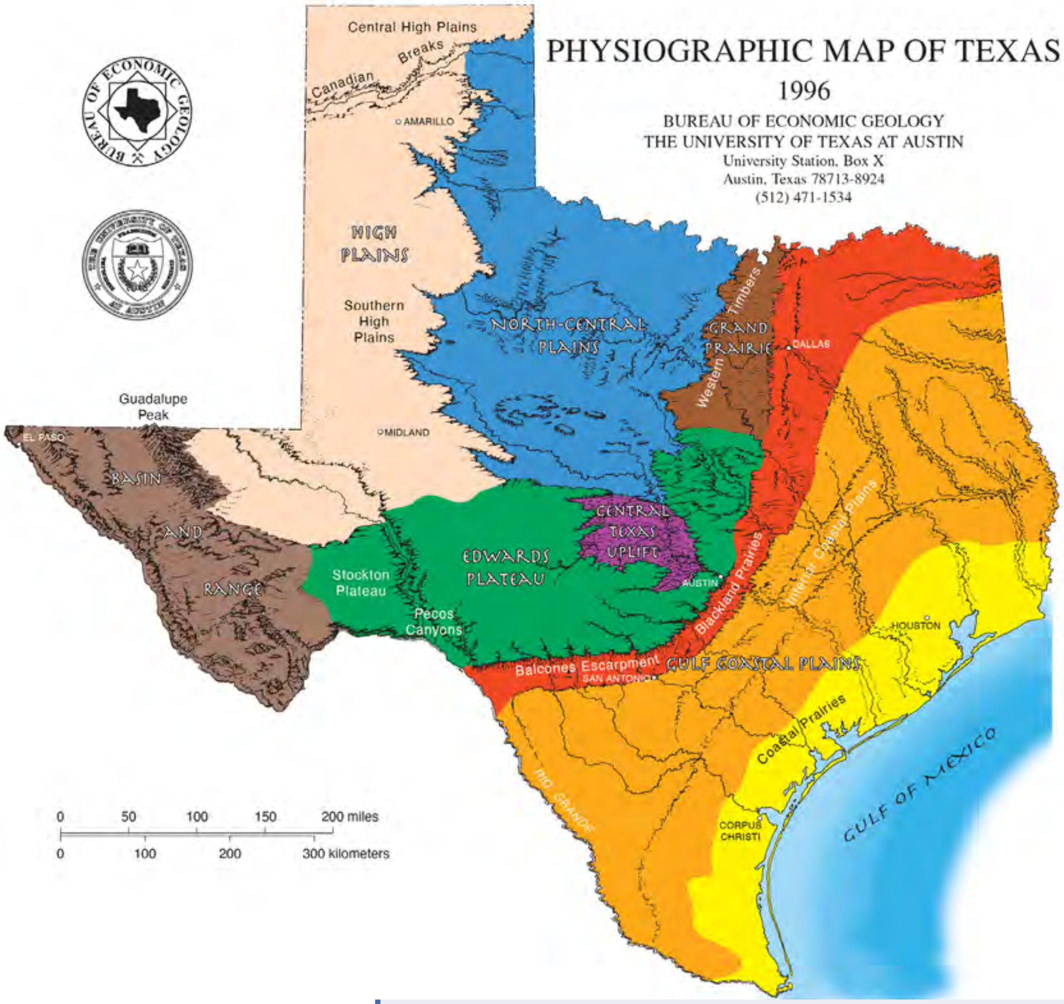


Figure 10. Physiographic province map of Texas. (Source: *www.beg.utexas.edu*)

Figure 11. High Plains of Texas.

This aquifer recharges very slowly because a layer of hardened caliche across the High Plains prevents water from seeping underground. The arid climate of the region also limits the amount of precipitation available for recharge.

More water is being extracted from the aquifer than is being added. The U.S. Geological Survey has estimated that the groundwater in the Ogallala was last in contact with the atmosphere 2,500 to 6,700 years ago. It appears that the younger water has already been pumped out, and the last time there was enough rainfall to recharge the aquifer was thousands of years ago.

Other aquifers are in this area at other depths, as shown in the major and minor aquifer maps.

Gulf Coastal Plains

From sea level at the Gulf of Mexico, the elevation of the Gulf Coastal Plains (Fig. 12) increases northward and westward to the Interior Coastal Plains and to the higher Blackland Prairies reaching 800 feet (shown as the yellow, orange, and red areas in Fig. 10).

Aquifers in the Gulf Coastal Plains developed as the Gulf of Mexico subsided and sea level rose and fell. During this period, unconsolidated sands and muds were deposited in a series of delta deposits like those discharged from the Mississippi River.

These wedges of sediment formed layers of well-sorted unconsolidated sediment, with layers of clay, sand, and silt that become thicker and deeper to the east and south. Layers of aquifers have formed from Corpus Christi to San Antonio to Dallas. The aquifers are separated by aquitards, which are underground bodies of geologic material such as clay that slow groundwater flow and are not permeable enough to yield water to a well.

The Coastal Plains extend westward to the Balcones Escarpment, which was formed by faulting along the Balcones fault zone. The fault zone is dominated by vertical faults that run nearly parallel to the Gulf Coast and represent the down-dropping and subsidence of the Gulf of Mexico.

About 1,500 feet of vertical subsidence has been measured along this fault. Hundreds of other faults lie between the

DID YOU KNOW?

The earth's water moves constantly at different speeds in different places and in different forms. Water is continuously being exchanged among the earth's surface, atmosphere, and the subsurface. It is found everywhere on the earth.

Figure 12. Gulf Coastal Plains of Texas.

escarpment and the Gulf shore, contributing to the tens of thousands of feet of subsidence over millions of years.

The major aquifers of the Gulf Coastal Plains are unconsolidated and trend from southwest to northeast, parallel to the coast and the Balcones Escarpment. Recharge occurs where the aquifers are exposed at land surface. It ranges from 0.79 inch per year to the south to 0.87 inch per year to the north, which has more precipitation.


Figure 13. Edwards Plateau.

The groundwater is younger where the Carrizo-Wilcox aquifer is exposed at the land surface. Isotope studies have confirmed that significant rainfalls recharge the aquifer. However, at a location 35 miles to the southeast, toward the Gulf, the water is 27,000 years old, meaning that it has been 27,000 years since that part of the aquifer has been recharged.

Several other aquifers are above and below the Carrizo-Wilcox with outcrops (and recharge zones) throughout the Gulf Coastal Plains.

Grand Prairie and the Edwards Plateau

Consolidated limestone bedrock underlies the Grand Prairie and Edwards Plateau (Fig. 13) of Central Texas (brown and green areas of Fig. 10). These two physiographic provinces range from 450 to 4,200 feet above sea level. The Edwards-Trinity limestone aquifer was formed 120 million years ago when the Gulf of Mexico covered most of the state.

As groundwater moves through the fractures and cracks in limestone, the rock dissolves, forming networks of caverns and sinkholes. When groundwater containing the dissolved rock moves into springs, a crust of calcium carbonate may form along the spring. High concentrations of dissolved calcium carbonate in groundwater will foul pipes and hot water heaters.

As this limestone bedrock dissolves, a landform is created called *karst topography.* Karst topography is characterized by caves, sinkholes, and underground drainage.

Water can move very quickly in karst, and recharge is nearly instantaneous. Rainfall in the province ranges from 15 to 33 inches per year, and groundwater levels can rise 5 feet or more after a weekend of rain.

Unfortunately, the aquifer can drain as readily, leaving it very vulnerable to drought. The communities of Austin and San Antonio are on the eastern margin of the Edwards Plateau.

North-Central Plains

Although limestone is found in parts of the North-Central Plains (Fig. 14), more predominant are layers of consolidated sands and shale that were formed at the same time. The North-Central Plains (blue area of Fig. 10) varies from 900 to 3,000 feet above sea level.

Erosion of these consolidated rocks has formed layers of unconsolidated alluvial deposits in the

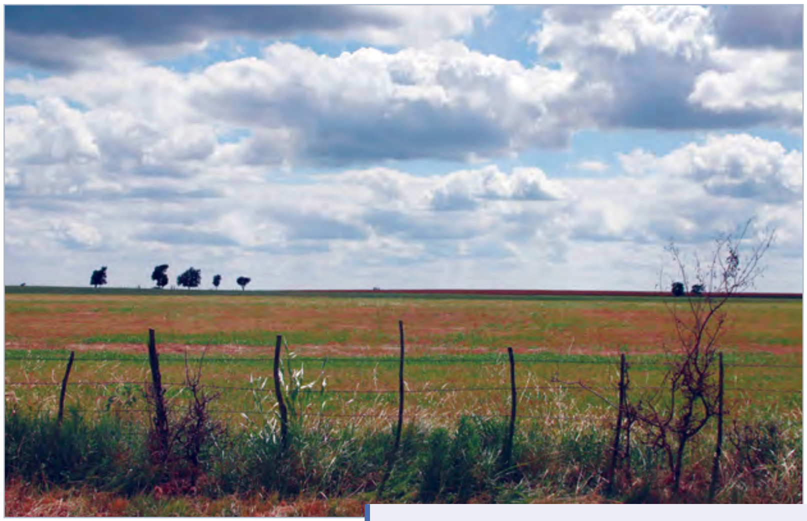


Figure 14. North-Central Plains of Texas.

Red and upper Brazos River Basins. Although these alluvial deposits are typically less than 100 feet thick, they provide an important source of water for domestic, municipal, and agricultural needs.

Annual rainfall averages 19 to 26 inches, and the rate of recharge depends on drainage and surface soil characteristics.

Basin and Range

Eight mountain peaks higher than 8,000 feet are in the Basin and Range province (Fig. 15 and dark-brown area of Fig. 10). At 8,749 feet, Guadalupe Peak is the highest point in Texas. The mountain ranges generally trend nearly north-south, parallel to the Rio Grande Rift structure.

Figure 15. Basin and Range province of Texas.

The mountain ranges consist of consolidated sedimentary, volcanic, or granite rocks. Volcanic rocks form many peaks in the province.

The sediments or alluvial materials that fill these valley basins originate from the mountains above, and typically consist of unconsolidated sands and gravels produced by the weathering of consolidated rock. The valleys are filled with materials produced by the action of erosion and transported by gravity and water, often forming large alluvial fans.

Impermeable geologic barriers prevented some of the basins from forming rivers that would drain the basin and create inland lakes. In these basins, the sediment may include deposits of silt, clay, and occasionally salt.

El Paso is the largest city in this arid region, where rainfall averages 9.4 inches per year. The groundwater in the Hueco Bolson aquifer is between 12,100 and 25,500 years old, suggesting that very little water is recharging the aquifer.

Central Texas Uplift: The Hill Country

The most significant characteristic of the Central Texas Uplift province is the rounded consolidated granite hills 400 to 600 feet high. Geologically identified as the Llano Uplift (commonly known as the Hill Country in Central Texas, Fig. 16), the ancient basement rock in this province is believed to be over 1.1 billion years old.

The province contains several minor aquifers consisting of consolidated sandstone and limestone; they are collectively referred to as the Llano Uplift Aquifers. Recharge enters through fractures and cracks along major fault zones, and water yield is low. The sediment eroded from the Central Texas Uplift formed much of the Gulf Coastal Plain aquifers to the east.

Figure 16. The Hill Country of Texas.

References

Bureau of Economic Geology, 1996. Physiographic Map of Texas. The University of Texas, Austin, TX. *www.beg.utexas.edu*

Huang, Y., B. R. Scanlon, J. Nicot, B. C. Reedy, A. R. Dutton, V. A. Kelley, and N. E. Deeds. 2012. "Source of Groundwater Pumpage in a Layered Unconfined-Confined Aquifer System in the U. S. Gulf Coast." Hydrogeology Journal.

Pearson F. J., and D. E. White. 1967. "Carbon 14 Ages and Flow Rates of Water, Carrizo A and Atascosa County Texas." Water Resources Research. 3:251–261.

Notes

4: Watersheds and Aquifers

A watershed is an area of land that water flows across, through, or under on its way to a stream, river, lake, or ocean. Each drainage system has its own watersheds, and all drainage systems and watersheds across the landscape are connected.

The boundary between any two watersheds is called a *divide* (Fig. 17). Watershed divides are defined by the highest point of an area of land—such as the top of a hill or mountain—that surrounds a drainage system or network of drainage systems.

All the land that drains water to a common drainage system is considered to be in the same watershed. Any water falling outside of a watershed divide will enter another watershed and flow to another point. In Texas, aquifers and watersheds typically have different boundaries.

Watersheds affect the quantity and quality of the water in aquifers. The water interacts with various parts of a watershed, including the soils, land use activities, and the aquifer.

All water on earth is constantly moving and recycling via an endless process known as the *water cycle* or the *hydrologic cycle* (Fig. 18). The hydrologic (water movement) cycle is driven by the energy of the sun and by the force of gravity. Water moves by evaporation, condensation, precipitation, transpiration (evaporation from plants), infiltration, and runoff.

In Texas, about 90 percent of all precipitation is lost through evaporation or plant transpiration; the other 10 percent either runs off into rivers and streams (Fig. 19) or moves into the soil and percolates as recharge to the aquifers below.

Several factors affect infiltration and recharge rates, including soil type, land use, topography, precipitation rates, available pore space, and aquifer characteristics. These factors can also affect groundwater quality.

Lifetime Water Needs

About two-thirds of the human body is made up of water, and a person living to the age of 70 will need about 1½ million gallons of water during his or her lifetime.

Figure 17. Watershed divides are the highest points of land that surround drainage systems.

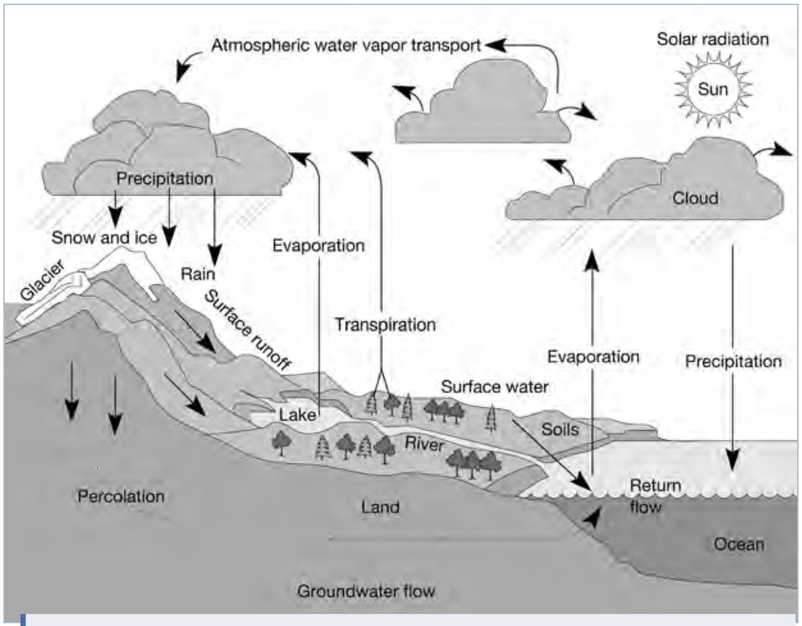


Figure 18. The water cycle. (Source: Dr. Fred Mackenzie, University of Hawaii at Manoa.)

Figure 19. The major river basins of Texas. (Source: *https://www.twdb.texas.gov/mapping/doc/maps/Major_River_Basins_8x11.pdf*)

Soil Type

The amount of moisture that a soil can hold depends on the soil's depth, texture, and structure. For example, much more water can infiltrate through sandy soils because they have large soil particles and large pores between the particles. Water drains more easily through large pores than through small pores. Clay soils slow the percolation rate and reduce the amount of recharge to the aquifer.

In arid areas, slightly acidic rain leaches calcium carbonate from the soil and then deposits it deeper in the soil. The calcium carbonate cements gravel and soil particles together to form a hard caliche layer. Caliche reduces the recharge rate significantly.

Land Use

Groundwater quality can be strongly influenced by land use activities such as landfills, dump sites, and failed septic systems (Fig. 20). Stormwater runoff

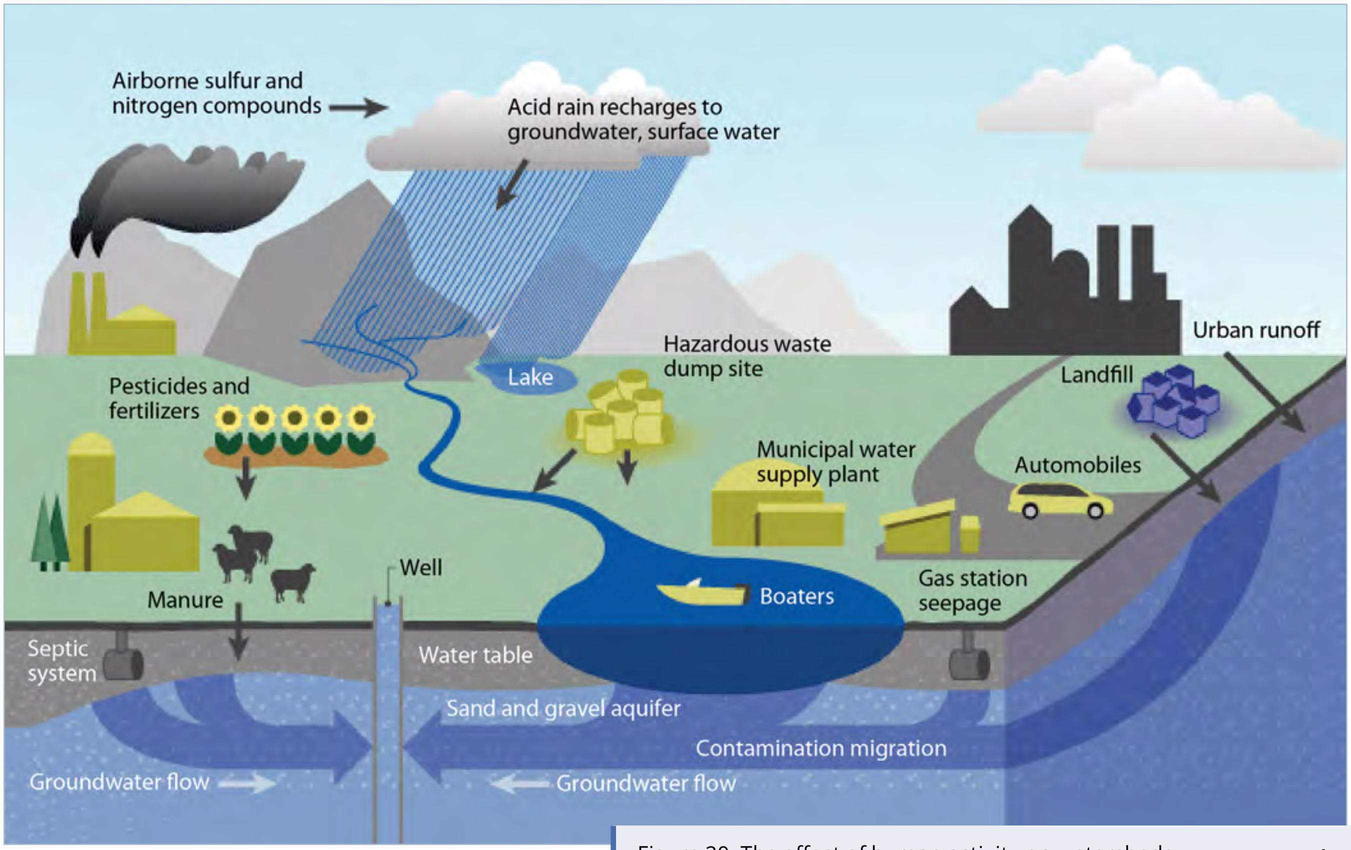


Figure 20. The effect of human activity on watersheds. (Image courtesy of Pollution Probe: Source Water Protection Primer, *https://www.pollutionprobe.org/water/*)

from urban areas transports contaminants that can percolate to the aquifer. If applied improperly, pesticides and fertilizers from home lawns, athletic fields, and agricultural lands can also contaminate water.

Aquifer recharge does not occur through impermeable surfaces such as roadways and parking lots. However, groundwater recharge can be increased in agricultural areas where imported water is used to irrigate crops.

Topography

Streams and rivers drain water to areas that often provide recharge to the underlying aquifer. The recharge in areas where surface water has accumulated in ponds or lakes is called *focused recharge.*

The area that contributes water to an aquifer is called the *catchment area.* The topography of a watershed directs water from rainfall to the aquifer. An example is the contributing area of the Edwards Aquifer, where the topography funnels surface water into stream beds and channels that then focus the recharge into the aquifer (Fig. 21).

Precipitation Rates

Aquifers in areas with little rainfall have less water available for recharge than those in wetter areas. Across Texas, the average precipitation rate varies from less than 8 inches per year in El Paso to almost 48 inches per year in Houston. The amount of natural recharge in the state ranges from 0.0004 to 5.8 inches per year.

Available Pore Space

If all the pore spaces and fractures are filled with water, no more recharge can occur. An aquifer can be recharged only when it has pore space to hold more water.

Aquifer Characteristics

Aquifer recharge rates also depend on the permeability of the soils and other materials. Permeability can vary significantly within the same aquifer type (Fig. 22).

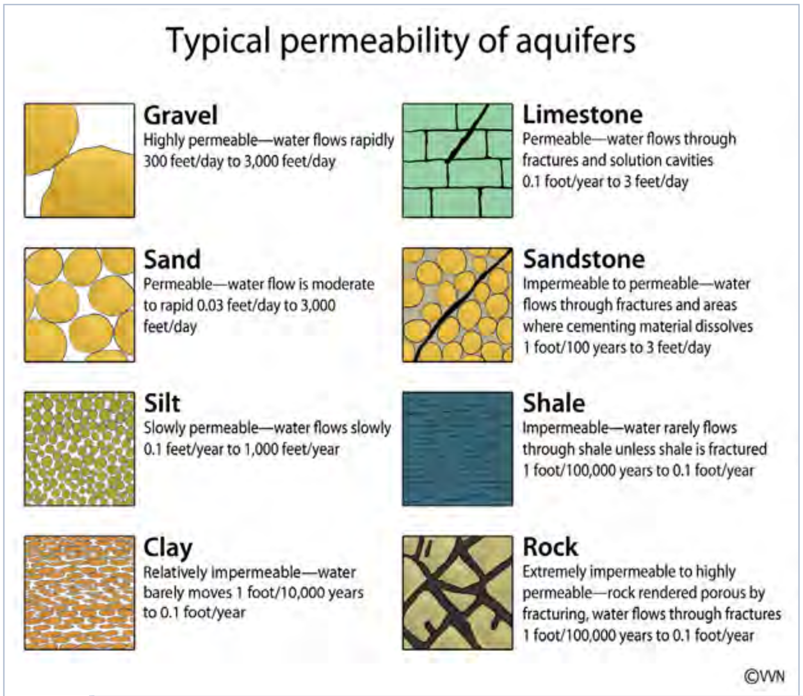


Figure 22. The characteristics of consolidated and unconsolidated aquifers determine the rate at which water can move through them.

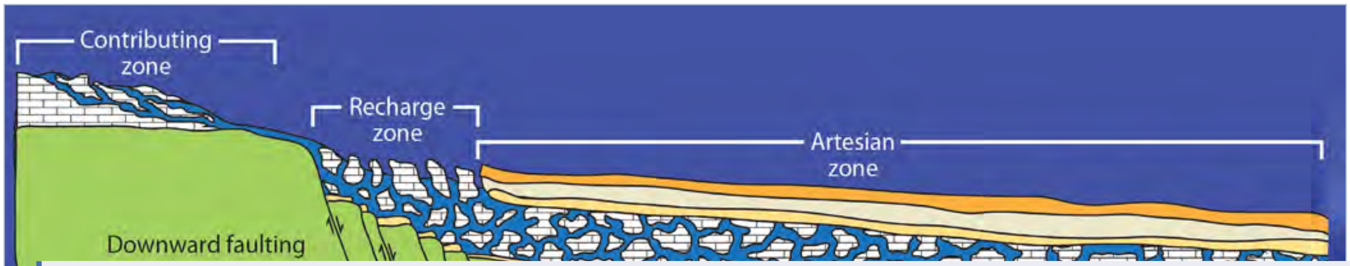


Figure 21. The contributing area of the Edwards Aquifer is the watershed above and upstream from the aquifer recharge area.

There are two types aquifers: confined and unconfined (Figs. 23 and 24).

- An **unconfined aquifer** receives recharge directly after each rain or snowfall.
- A **confined aquifer** is covered with an aquitard, which is geologic material that is not very permeable. The material prevents water from entering the aquifer directly.

Sometimes the pressure in a confined aquifer is great enough to cause the water to rise above the aquitard. In these conditions, the well becomes *artesian.* If the pressure moves the water to the ground surface, the artesian well is called a *flowing well.*

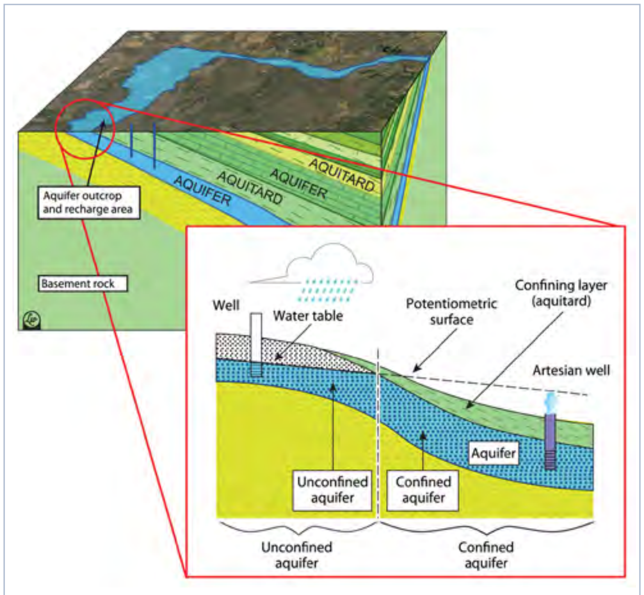
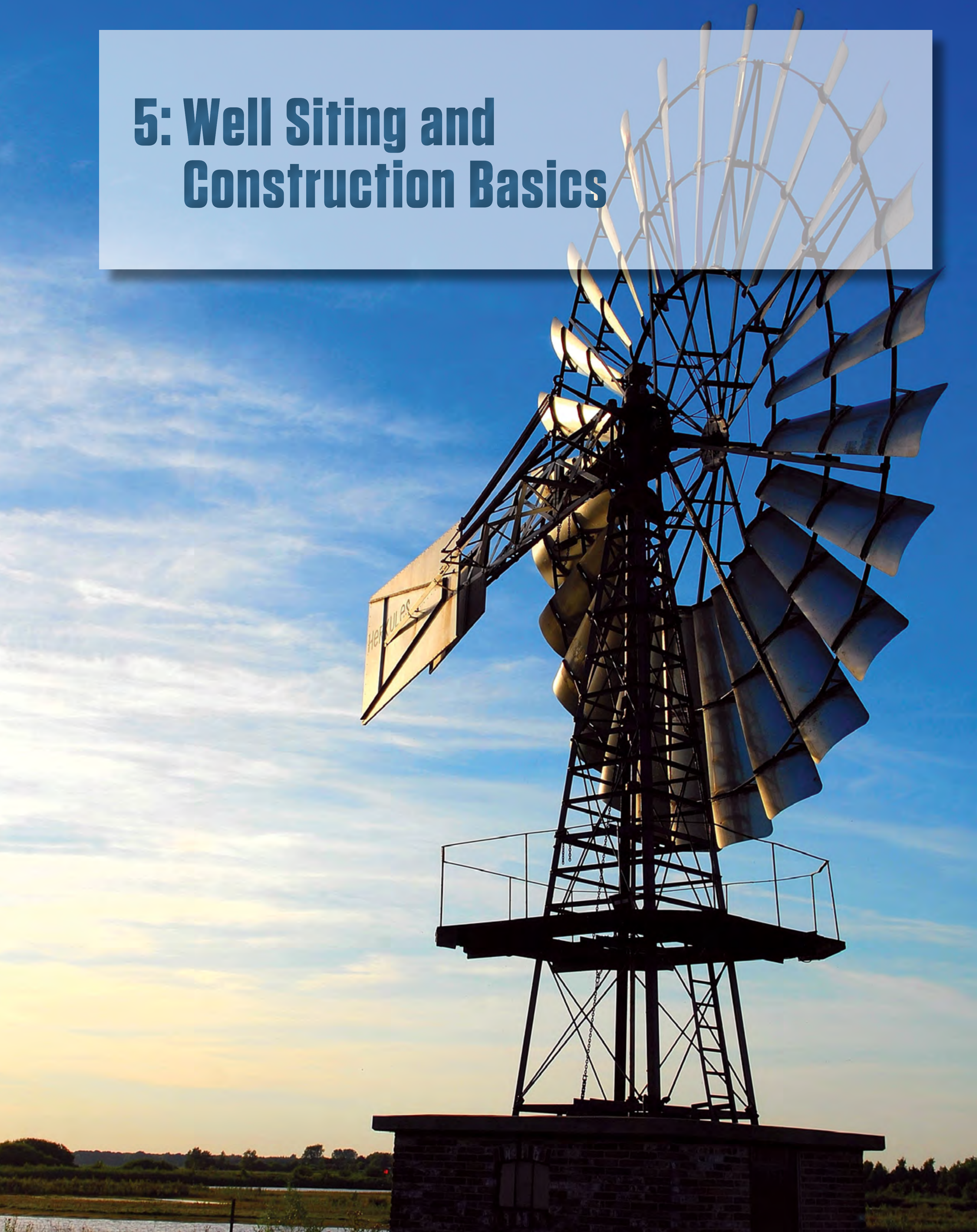


Figure 23. Artesian wells are found in confined aquifers where the water level rises in the well above the confining geological material.

Figure 24. A flowing artesian well in Hallettsville, Texas.
Source: Fey and Braunig. Artesian Well, Photograph, n.d.; digital images, (*texashistory.unt.edu/ark:/67531/metapth128796/m1/1/*), University of North Texas Libraries, The Portal to Texas History, *texashistory.unt.edu*; crediting Friench Simpson Memorial Library, Hallettsville, Texas.

Notes

5: Well Siting and Construction Basics



Texas has strict requirements for siting and building wells and for submitting well drilling completion reports. The construction and licensing requirements are administered through the Texas Department of Licensing and Regulation (*www.tdlr.texas.gov*).

Local groundwater resources may be managed and protected through the creation of groundwater conservation districts (GCDs). The state also encourages joint planning between these districts.

Texas has 16 groundwater management areas (Fig. 25) that were created by the legislature to conserve and protect groundwater and to control subsidence (sinking) caused by the withdrawal of water from groundwater reservoirs (Texas Water Code §35.001).

Within the 16 areas, there are currently 100 groundwater conservation districts created locally by voters. Each district must develop and implement a plan to manage groundwater resources effectively. The plans must be approved by the Texas Water Development Board.

As of 2015, all confirmed districts had an approved management plan or were in the approval process. To determine if you are located within a GCD, and for more information about GCDs, visit *http://www.twdb.texas.gov/groundwater/conservation_districts/index.asp*.

A local GCD may set rules for drilling new water wells in addition to the state regulations. All well drillers and pump installers must be licensed and registered with the state through the Texas Department of Licensing and Regulation and will be familiar with local requirements.

To find a licensed well driller/pump installer in your area, visit *www.tdlr.texas.gov/LicenseSearch/*.

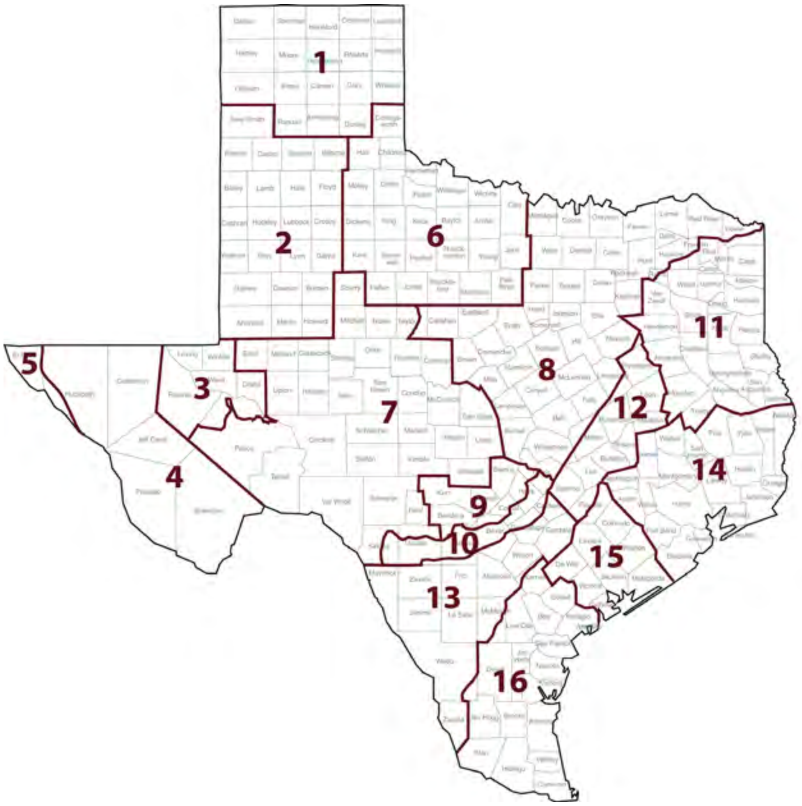


Figure 25. The 16 groundwater management areas in Texas. (Source: *www.twdb.texas.gov/groundwater/management_areas/*)

Information About Your Well

The landowner is responsible for managing the drinking water from a domestic well. To begin protecting your water supply, record the locations of all well(s) on your property, and maintain a file of all well records.

Each well has unique five- or six-digit well identification number assigned by the driller. You can use the number to find historical information about the well from the following sources:

- **Texas Water Development Board (TWDB) Groundwater Database**

  Licensed water-well drillers must submit reports to the state on each well drilled. Of the 1 million plus water wells drilled in Texas over the past 100 years, more than 130,000 have been inventoried and the data entered into the TWDB groundwater database since 2001.

The database lists the well type, diameter, geology, yield, type of construction, and other details about the well and location. You may be able to find your well at *https://www3.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer*.

- **Texas Commission Environmental Quality (TCEQ) Water Well Report**

  The TCEQ may have information about your well in its map-based database at *https://tceq.maps.arcgis.com/apps/webappviewer/index.html?id=aed10178f0434f2781daff19eb326fe2*.

  If your well report is not online, it may be available from the TCEQ Records Services Department in Austin (512-239-4600).

- **Groundwater Conservation Districts**

  If your well is located within a groundwater conservation or subsidence district, the district may have more information about your well. Find out at the Texas Alliance for Groundwater Districts (*www.texasgroundwater.org/*) or the Texas Water Development Board.

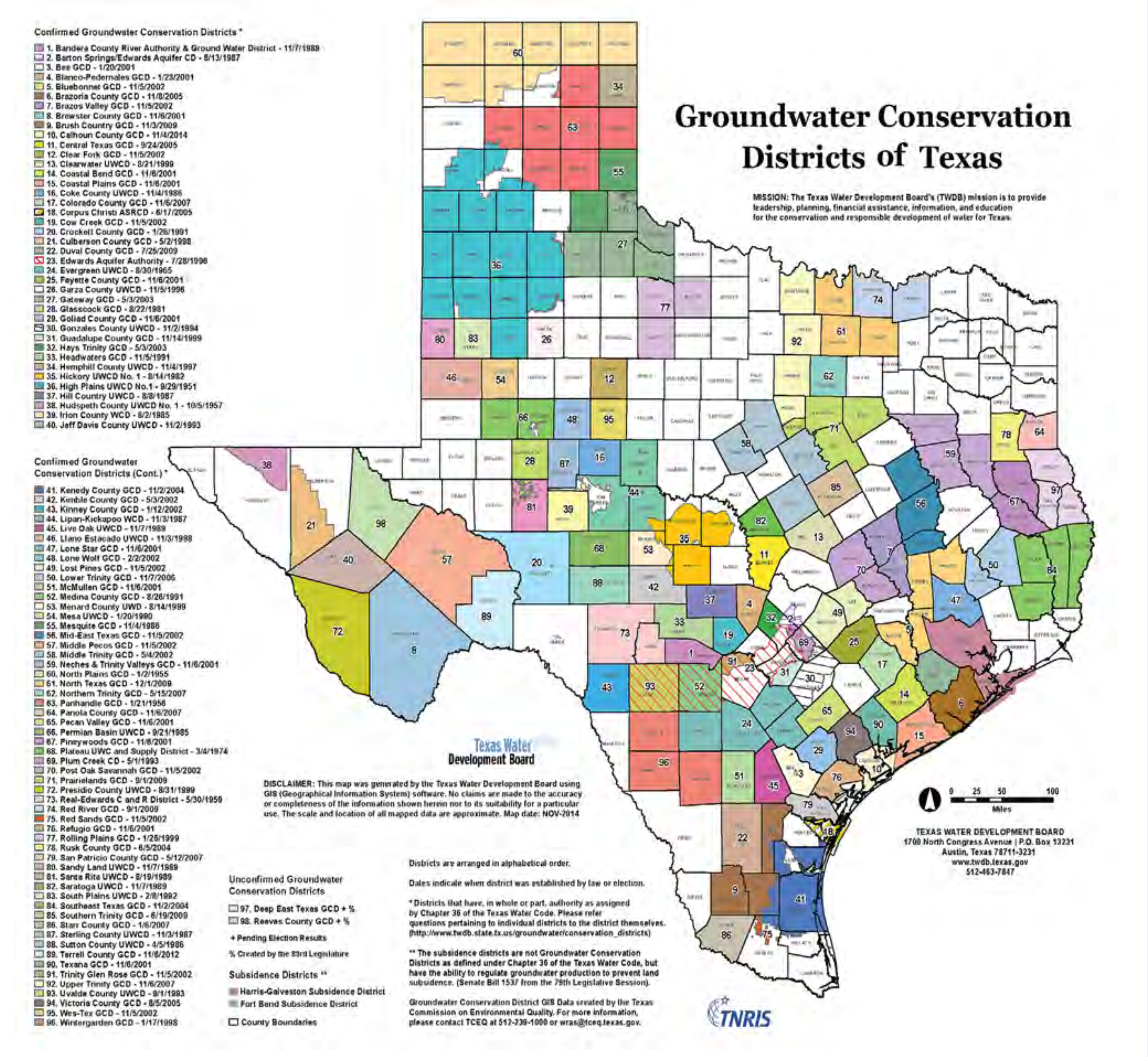


Figure 26. The groundwater conservation districts in Texas. (Source: *https://www.twdb.texas.gov/mapping/doc/maps/GCDs_8x11.pdf*)

Well Siting Regulations

The state has set limits on how close a well can be to potential sources of contamination (Fig. 27). The wellhead must be at least:

- **50 feet** from any septic tank, cistern, property boundary, and/or nonpotable well
- **100 feet** from a septic drain field or any leach field
- **150 feet** from any shelter or yard for pets or livestock, feed storage facility, and pesticide or fertilizer storage
- **250 feet** from a liquid waste disposal system or manure stack

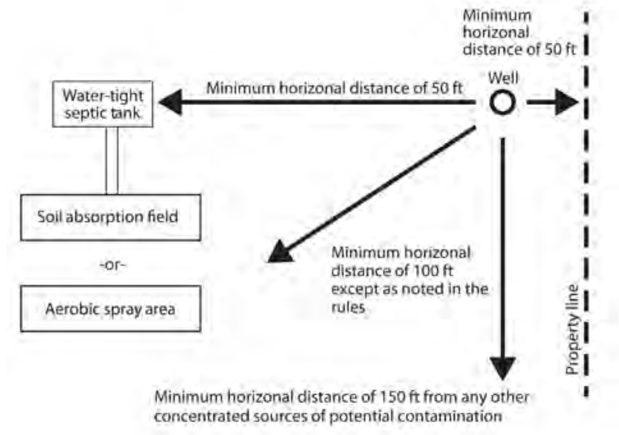


Figure 27. Well location from potential contaminant sources.

In addition, every effort must be made to locate a new well where it will not be vulnerable to flooding. Floods can cause the contaminants from the surface to seep down the outside of the well casing and pollute the aquifer.

The Texas Department of Licensing and Regulation enforces well construction regulations through its licensing and registration processes for water well drillers and pump installers. The agency is responsible for ensuring that drillers and installers comply with regulations to protect your private drinking water supply.

A well driller will know to build a new well at an optimal site based on local experience and knowledge of fracture zones and fault lines. If the well is in an unconsolidated aquifer, its characteristics are unlikely to differ much across a property. However, the amount and quality of water from a well can differ significantly at various well depths.

In contrast, the yield from consolidated aquifers can change dramatically over short distances: A good-yielding well can be located just a few yards from a dry hole. To increase a well's yield, the driller may recommend drilling deeper or enlarging the diameter of the borehole, or hydraulic fracturing the well.

Well Construction

To maintain a household well properly, you need to know the components of a home water supply system and their functions. In addition to pumps, these components include well casings, grout, concrete pads, well caps, well screens, gravel packs, pitless adapters, and storage tanks (Fig. 28).

Well Casing

The well casing is a pipe placed in the borehole. The casing keeps the well open and helps prevent the mixing of materials from different zones of the aquifer. Within the casing is the drop pipe, which carries the water to the surface, and the electrical wiring to the submersible pump.

In Texas, a modern domestic well may have one or two well casings: the actual well casing and, occasionally, a tubular outer casing made of steel or PVC pipe. Many wells have only one casing.

State regulations require that the casing(s) extend at least 1 foot above the land surface. Underground, the casing may extend to the full depth of the well or, in a consolidated rock aquifer, only 100 feet through broken rock, leaving an open rock borehole as the well. The borehole diameter must be at least 3 inches larger than that of the well casing.

A surface seal must extend at least 10 feet below the land surface, filling the space between the well casing and the borehole. This space is known as *annular space.* As the well is being built, the driller will install spacers in the annular space to make sure that the well casing does not lean.

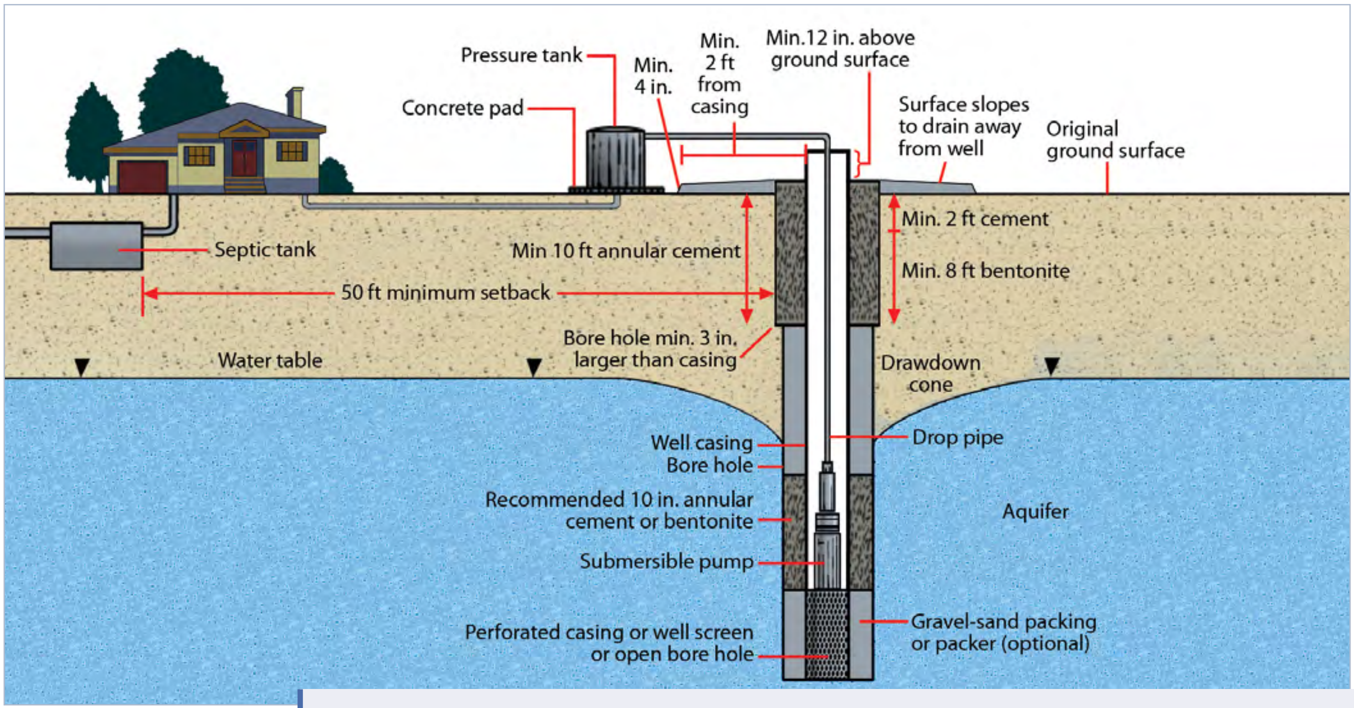


Figure 28. Domestic well diagram. Well construction and plugging specifications accepted by the Texas Department of Licensing and Regulations are shown at *https://www.tdlr.texas.gov/wwd/wwdspecs.htm*.

Well casings for household wells can vary from 4 to 8 inches in diameter, depending on the aquifer conditions and the type of pump to be installed. The most common materials for well casings are carbon steel, plastic (usually PVC), and stainless steel. PVC is lightweight, resistant to corrosion, and relatively easy to install.

To minimize the risk of contaminating the well water with solvents, PVC casing sections should be joined without glues. Although they are more expensive, mechanical couplings or threaded pipe fittings should be used when possible.

Steel is susceptible to corrosion and can develop scale in hard water. Some well casings are made of concrete, fiberglass, or asbestos cement. Older wells may be hand-dug and cased with hand-placed bricks or stone.

Grout

Cement grout is used to seal the upper part of the well and prevent contaminants from draining from the surface down along the well casing and into the aquifer.

The grout consists of cement slurry and may include different types of clay; the licensed driller will follow local rules and make sure that the construction is appropriate to local geologic conditions.

Concrete Pad

Texas law requires that there be a concrete pad or block at the wellhead that extends laterally at least 2 feet from the well in all horizontal directions. The pad must be at least 4 inches thick. To prevent water from pooling at the wellhead, the pad should slope away from the well casing.

Cap

A wellhead seal or cap on top of the well casing helps keep debris, insects, and small animals out of the well system. Well caps (Fig. 29) are usually made of aluminum or a thermoplastic, and include a vented screen to equalize the pressure between inside and outside the well when water is pumped out. The cap should fit snugly.

Figure 29. Example of a well cap made of aluminum.

Well Screens

Well screens help prevent sediment from entering the well. The screen allows water to move through the well while keeping out most of the sand and gravel. The most common screens are made of slotted or perforated pipe (Fig. 30).

A *continuous slotted well screen* is made of wire or plastic that is wrapped around a series of vertical rods. *Perforated pipe* has slots drilled at set distances into steel or plastic. Perforated pipe should not be used in aquifers that contain fine-grained alluvial materials because it would allow sand to fall into the well.

Well screens are manufactured with specified openings and slot diameters to accommodate local geologic conditions. They are placed only in the saturated part of the aquifer. The well and well screen may be damaged if the groundwater elevation drops and air enters the screened area.

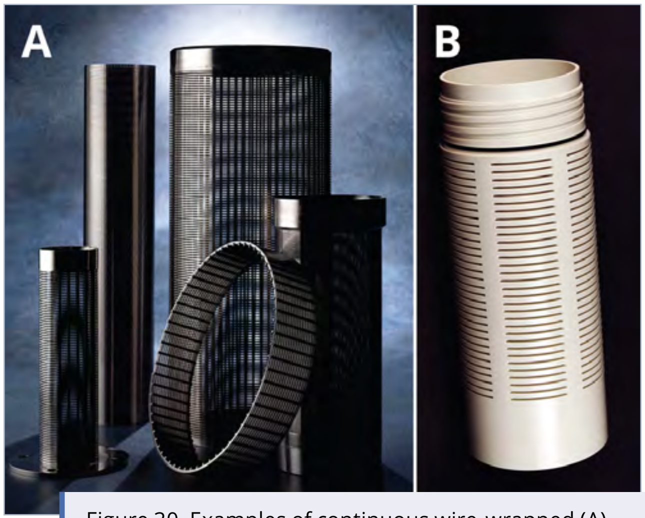


Figure 30. Examples of continuous wire-wrapped (A) and slotted PVC screens (B). Reprinted by permission of Johnson Screens, a Weatherford Company.

Gravel Packs

While a well is being installed, a gravel pack is typically placed in the annular space outside the screen casing. The gravel pack helps prevent sediment from entering the well. The grains of sand or gravel are too big to pass through the screen slots but are smaller than those of the surrounding soils or unconsolidated aquifer materials.

Gravel packs also slow the water passing through the aquifer and into the well. If the water is moving too fast because of excessive pumping or an improperly sized gravel pack, it will pull sediment into the well and erode the aquifer.

A process called *well development* can protect the household water system from future sediment problems. Fine-grained materials are removed from around the well and the annular space between the casing and borehole wall (Fig. 31).

Screens are usually not needed for wells in consolidated bedrock aquifers because the boreholes in bedrock remain open.

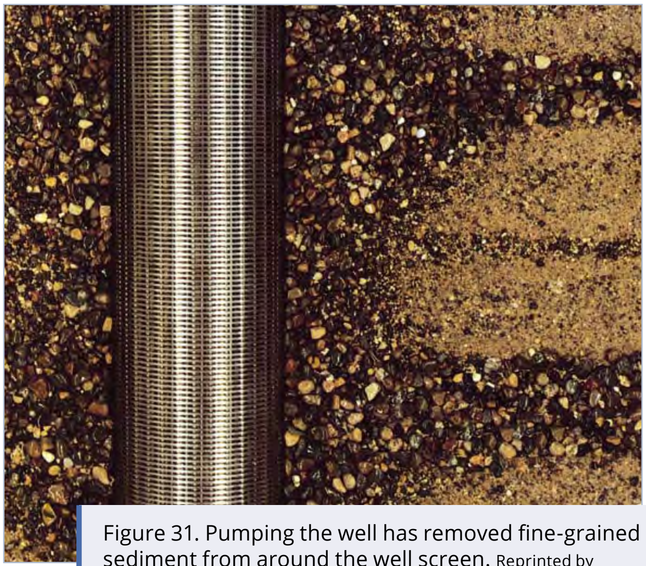


Figure 31. Pumping the well has removed fine-grained sediment from around the well screen. Reprinted by permission of Johnson Screens, a Weatherford Company.

Pitless Adapters

Pitless adapters prevent water pipes from freezing in the winter. The adapters provide a sanitary, frost-proof seal between the well casing and the water line running to the house. The adapter is connected to the well casing below the frost line (Fig. 32). The adapter diverts the water from the well horizontally to prevent it from freezing, and the plumbing continues underground.

Storage Tanks

Most home water well systems have a pressurized tank that stores water for periods of heavy usage (Fig. 33). The tank has extra water on reserve so that small demands do not continually activate the pump.

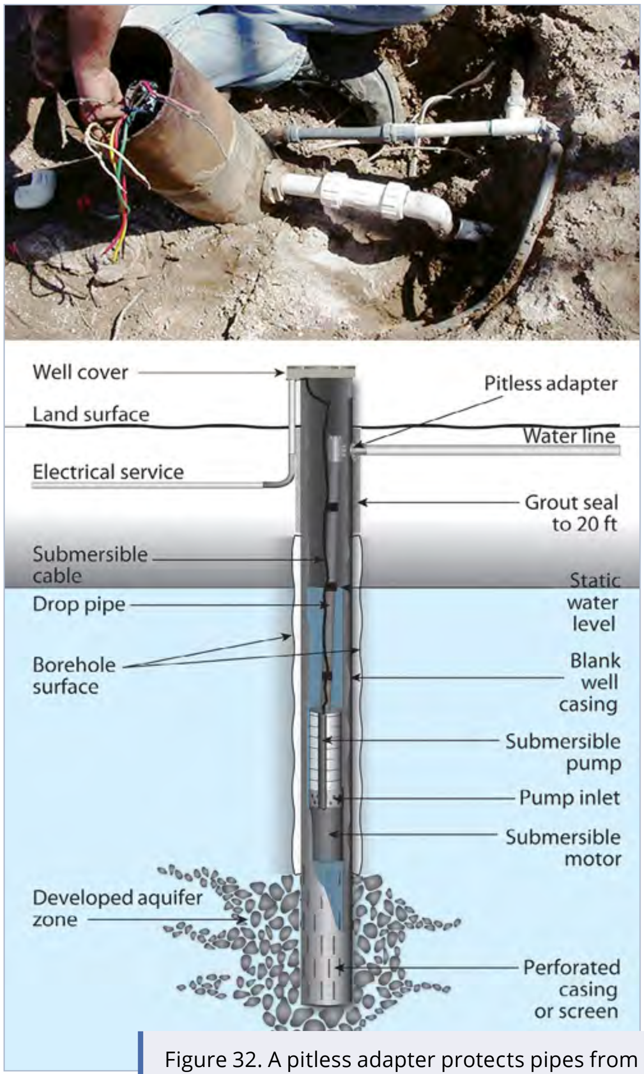


Figure 32. A pitless adapter protects pipes from freezing in cold weather. (Source: Gary Hix)

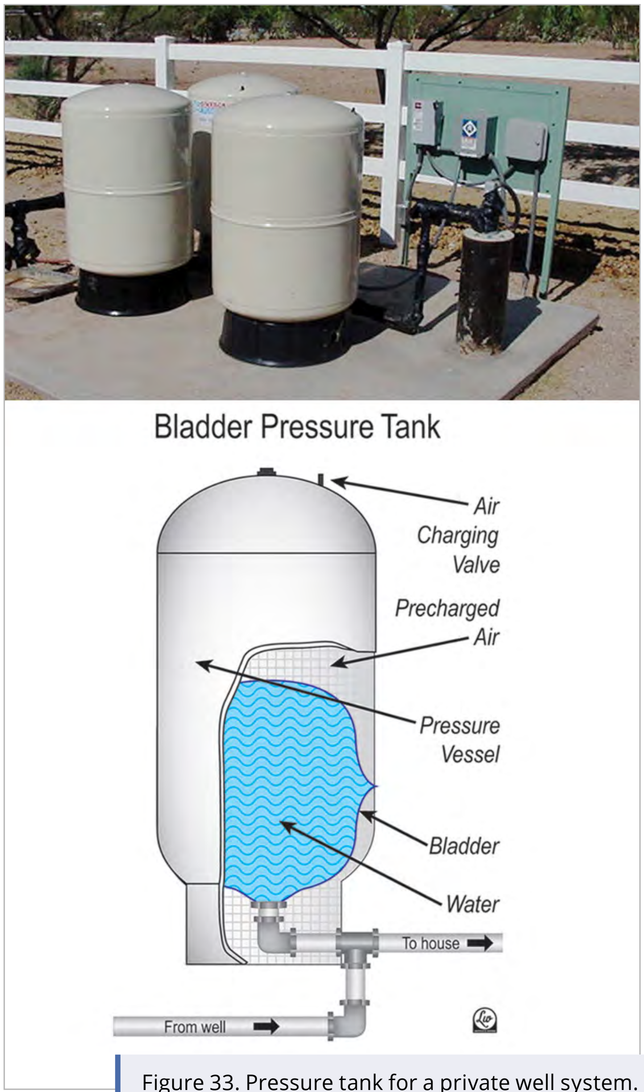


Figure 33. Pressure tank for a private well system. (Source: Gary Hix)

How Wells Affect Aquifers: Cones of Depression

As water is pumped from a well, the groundwater elevation around the well drops, typically in the shape of an inverted cone. The cone is known as a *drawdown cone* or a *cone of depression* (Figs. 28 and 34).

The shape and size of the cone depend on the type of aquifer it is in:

- In an unconsolidated, porous aquifer, the cone of depression forms around the wellhead in an ever-expanding circle as more water is pumped from the aquifer.

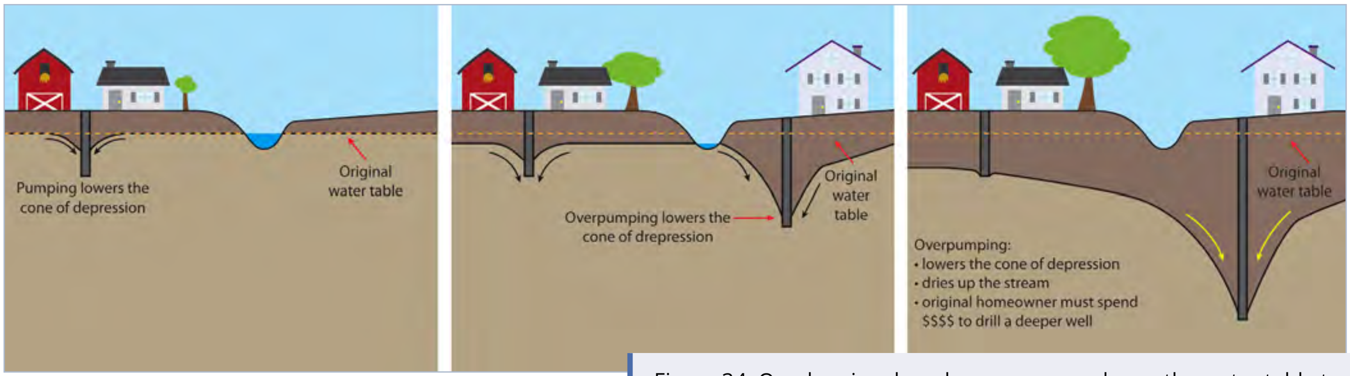


Figure 34. Overlapping drawdown cones can lower the water table to the point where neighboring homeowner wells and rivers can go dry.

- In a consolidated, fractured rock aquifer, the cone of depression follows the underground fracture system and may take an unpredictable shape as the cone expands outward to pull more water into the well.
- In an artesian system, the cone may extend for hundreds of feet.

Several problems can arise from cones of depression:

- Water and contaminants in the cone around the well can eventually be captured and drawn into the well and water supply system.
- If the cone extends beneath a river or stream, the well will begin pumping river water from the riverbed, through the aquifer, and into the well.
- If the cone extends out and beneath a source of pollution, such as a landfill or a leaky gas station storage tank, the well may draw the contaminants into the well.
- If a cone intercepts a neighboring cone of depression from a nearby well, both wells may run dry faster.

If the water level recovers slowly after pumping, the well may temporarily run dry when too much water is used, such as over a weekend. The residents should use the water more uniformly throughout the week or month to prevent this problem as well as to avoid overheating the pump and causing permanent damage.

Well System Failure

All well systems are vulnerable to mechanical failure that can lead to pollution of the water supply. The water can become contaminated because of corroded pipe, broken surface seals, and standing water that seeps back into the aquifer along the outside of the well casing.

Pump or plumbing failure should always be addressed by a licensed well professional. Figure 35 shows a pump that failed after being corroded by stray electrical currents.

Figure 35. Stray electrical currents formed a hole in this submersible pump. Water was forced through the hole in the bottom of the pump, causing the well screen to collapse and the well system to fail. (Source: Mike Prestigiacomo)

In Texas, the most common cause of water well system failure is dropping groundwater elevations. If the water table drops below the well casing, air mixes with the water, causing turbulence in the water and erosion in the aquifer.

The first sign of system failure—and dropping groundwater elevations—is the buildup of sediments in tanks, pipes, and plumbing fixtures (Fig. 36). If the well continues to pump gritty sands, the pump itself can be damaged and have to be replaced.

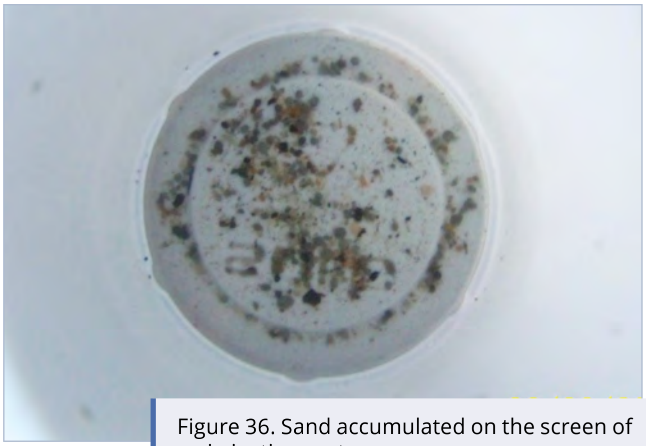
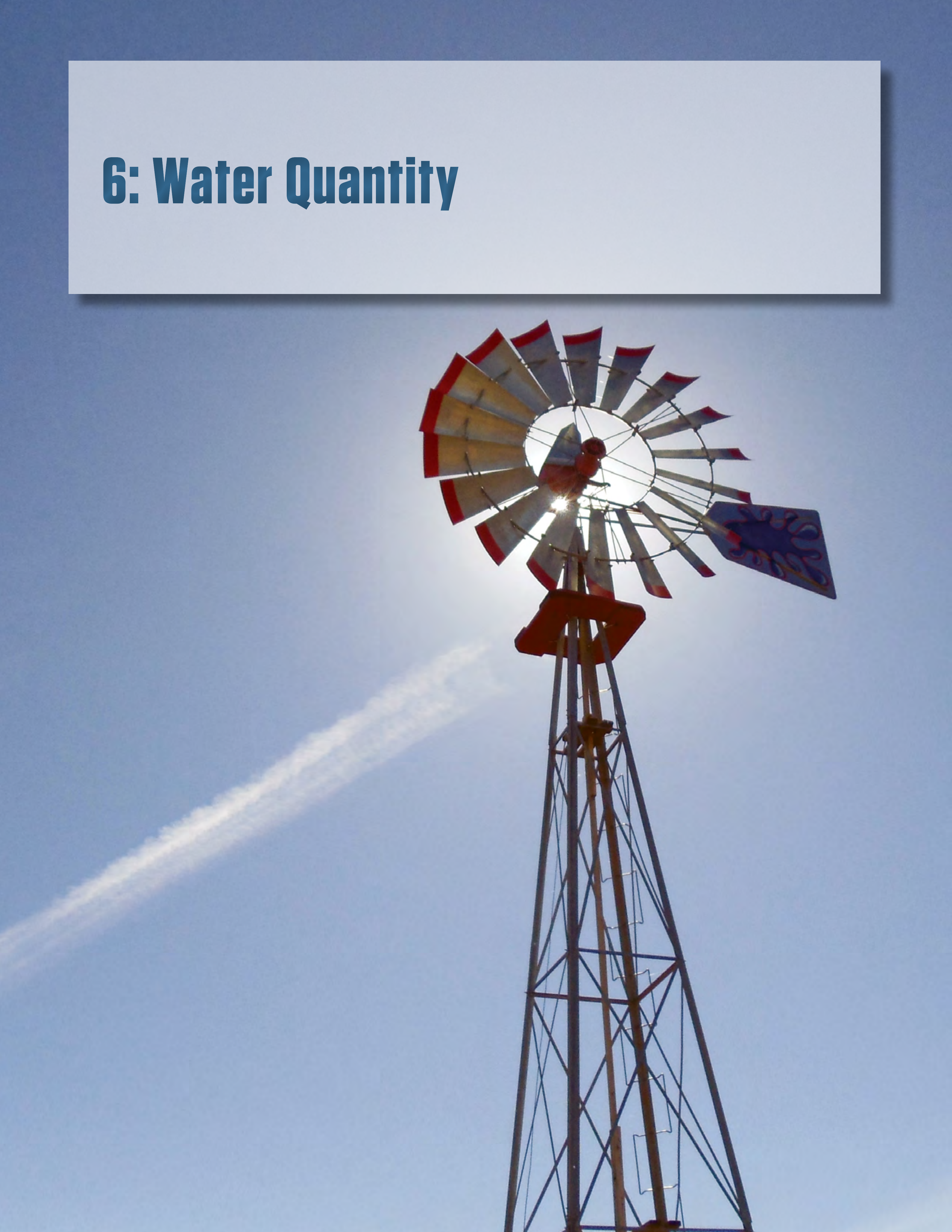


Figure 36. Sand accumulated on the screen of an irrigation system. (Source: Mike Prestigiacomo)

Notes

6: Water Quantity



After a well is built and the pump installed, the licensed well driller will pump the well to test its ability to produce water and to remove any fluids—such as chemical drilling muds used to facilitate drilling—from the aquifer.

Well yield is the rate at which a well can be pumped without drawing the water level down to the pump intake. Well yield is measured in gallons per minute (GPM).

The well must be designed and built to yield water at a pumping rate that meets the needs of the water well owner. Whether the well can yield enough sustained water supplies depends greatly on the aquifer's characteristics, the depth from the ground surface to water, and the construction and maintenance of the well.

Texas Water Code §§ Section 36.117(b) identifies a household well as *"exempt from regulation when used solely for domestic use or for providing water for livestock or poultry on a tract of land larger than 10 acres that is either drilled, completed, or equipped so that it is incapable of producing more than 25,000 gallons of groundwater a day."*

If a well is pumped constantly at a rate of 17.4 GPM, it will reach the maximum 25,000 gallons per day (GPD), and would be considered exempt use. Groundwater conservation districts may, by rule, exempt any other category of well use.

Figure 37. Drilling and installing a well. (Source: Gary Hix)

Figure 38. The first water well near Port Arthur, Texas. Photograph, n.d.; digital images, (*texashistory.unt.edu/ark:/67531/metapth79168/*), University of North Texas Libraries, The Portal to Texas History, *texashistory.unt.edu*; crediting Port Arthur Public Library, Port Arthur, Texas.

In consolidated bedrock or finer grained alluvium, wells have been known to yield only 3 to 5 GPM for household use.

Texas Water Rights and Groundwater Ownership

Texas groundwater law is based on the English common-law doctrine that associates groundwater with the landowner. Since 1904, Texas courts have applied the "rule of capture" to determine who is liable for damages relating to the withdrawal and use of groundwater.

This doctrine and its interpretation essentially provide that groundwater, once it has been captured by a well and delivered to the surface, belongs to the landowner. As such, landowners may use or sell all the water they can capture from below their land.

Texas courts have consistently ruled that landowners may pump as much water as they want from beneath their land, regardless of how it affects neighboring landowners' wells. As recently as February 2012, the Texas Supreme Court confirmed that the landowners own the groundwater beneath their property.

Over the years, the courts have placed only a few limitations on the rule of capture, including:

- Landowners are liable for damages if their negligent pumping of groundwater causes neighboring land to subside.

- A landowner may not drill a well on someone else's property or drill a "slant" well that crosses the property line to adjoin property.
- Groundwater cannot be captured or used maliciously to injure a neighbor or amount to willful waste of the resource.
- Groundwater pumping may not result in polluting a groundwater reservoir by saltwater or other substance.
- Landowners may not willfully cause or knowingly permit the water from an artesian well to run off the well owner's land or to percolate through a layer above which the water is found.

No state agency has the authority to regulate the production or use of groundwater beyond the limitations listed above. However, in 1949 the Texas Legislature provided for the voluntary creation of GCDs. Legislation in 1985 and 1997 established that locally controlled GCDs are the state's preferred methods for managing groundwater resources.

Groundwater conservation districts have some powers that can give communities some ability to modify the rule of capture. A district may make rules, including limiting groundwater production based on acre tract size or the spacing of wells. Landowners outside of these districts have little recourse in protecting their groundwater or in limiting the effects of groundwater pumping by neighbors or others.

Even if a well is exempted from permitting, according to Section 36.117, the well still must (1) "*be registered in accordance with rules promulgated by the district*" and (2) "*be equipped and maintained so as to conform to the district's rules requiring installation of casing, pipe, and fittings to prevent the escape of groundwater from a groundwater reservoir to any reservoir not containing groundwater and to prevent the pollution or harmful alternation of the character of the water in any groundwater reservoir.*"

Exempt household well owners in groundwater conservation districts cannot sell their water or pump more than 25,000 GPD. Those actions would change the designation of the well; the owner would have to pay fees and follow the water-rights procedures of the new use category in the district.

DID YOU KNOW?

The amount of water at the earth's surface has remained fairly constant over geologic time, cycling among the reservoirs of the atmosphere, streams, lakes, ocean, glaciers, and groundwater.

The local GCD can set restrictions and fees for other categories of water use, including agricultural, industrial, and/or municipal uses.

Shared Wells

Wells that provide drinking water for community water systems are regulated by state and federal law. These well-based water systems have the potential to serve at least 15 residential service connections year-round or at least 25 residents year-round.

Domestic wells that serve water to fewer than 15 connections or 25 residents are not required to comply with drinking water quality standards or reporting rules. In Texas, these wells are known as private domestic *shared wells* and are exempt from regulation.

People using a shared well should enter a legal agreement to:

- Protect access to the water supply
- Stipulate costs and responsibilities for well maintenance
- Address the operation of the well and water distribution system
- Set annual fees and shared expenses
- Require that the well water be tested annually to make sure it is safe to drink

For an example of a shared well agreement recommended by the U.S. Department of Housing and Urban Development, visit the agency's website at *www.hud.gov*.

Low-Yielding Wells

Low-yield wells are susceptible to problems in water quality. When the water level changes often, the pump is more likely to cycle on and off, which introduces oxygen into the aquifer. Minerals in the aquifer that are exposed to oxygen can dissolve into the groundwater. If the aquifer contains arsenic minerals, for instance, the water may contain more dissolved arsenic.

Several factors can reduce a well's yield:

- Lowered water tables
- The development of scale in the well and screen (Fig. 39). Like the deposits often found on household faucets, scale is the hard residue that coats the inside of pipe and the well screen.
- The accumulation of bacteria that plug the pores in the aquifer and the opening of the well screen.

In extreme cases, the combined effect of scale and slime has been reported to reduce well yield by 75 percent within a year of well operation. Bacterial slime (bioslime) can also cause serious health problems (see Chapter 8).

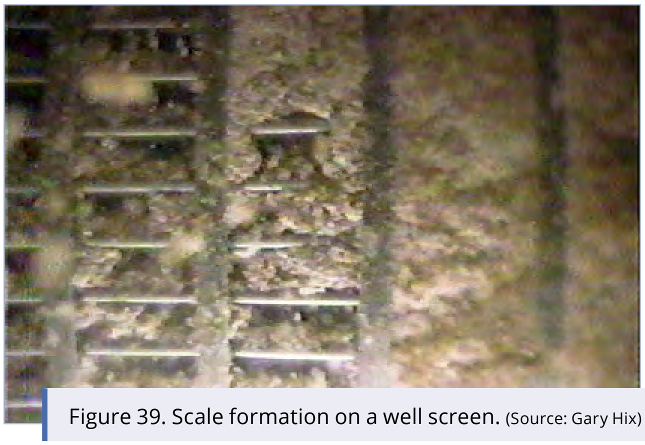


Figure 39. Scale formation on a well screen. (Source: Gary Hix)

Options for Correcting Low-Yield Wells

To correct a low-yield well, you need to know the cause of the problem and the type of aquifer involved. The options include deepening the well, hydraulic fracturing, shock-chlorinating, adding dry ice, scrubbing, and redeveloping the well.

Well deepening: If the static water table elevation has dropped, you may be able to increase yield by having the well deepened or the pump lowered.

Hydraulic fracturing: Open-borehole wells, such as those in consolidated bedrock, may yield more water if they are "fracked." In this procedure, parts of the well are sealed and the pressure in the borehole is raised enough to fracture the rock. Increasing the number of fractures around the borehole may give the well access to more water-bearing fractures and may increase yield.

Shock chlorination: A well plugged with bacterial slime can be shock-chlorinated to kill the bacteria and improve its yield. Hire a qualified water well contractor to shock-chlorinate the well instead of trying it yourself.

Carbon dioxide: Some well owners have increased their well yields by dropping dry ice into the wells. As the carbon dioxide bubbles from the dry ice, the water becomes more acidic, which dissolves part of the carbonate-based scale and kills some of the bacteria. The agitation of the bubbling dry ice in the borehole may also loosen some of the particulate scale.

Municipal water systems are beginning to use pressurized carbon dioxide gas to sanitize their well systems. The downside of using carbon dioxide is that acidifying the water can corrode the pipes.

Scrubbing: In wells that have scale or slime buildup, the most efficient way to increase yield is to scrub the interior of the well casing and screen. In this procedure, a licensed pump installer mobilizes a pump rig over the well, removes the pump and any interior plumbing, and scrubs the well with equipment similar to a large bottle brush.

If pump maintenance activities allow open access to the well, it should be scrubbed to remove scale, slime, and other materials.

Redevelopment: Another option to improve yield is to redevelop the well, as discussed in Chapter 5. To find a licensed well driller/pump installer in your area, see *www.tdlr.texas.gov/LicenseSearch/.*

Drought

Water tables often drop during severe droughts, and some low-yielding aquifers that don't recharge quickly may be responding to a drought that occurred decades ago. Take these steps to help protect your well during a drought:

- **Monitor your pump for rapid cycling:** One sign of lowered water tables is the rapid turning on and off of the pump over short periods. This rapid cycling can burn out the motor, and the heat generated by a submersible pump can damage the drop-pipe if it is made of PVC. Allow the pump to rest or, if possible, reduce the pumping rate.

- **Listen to the pump:** If pumping causes the sounds of "sucking air," turn the pump off and allow it to rest.
- **Check for sand in the toilet tank:** When the water table is drawn down below the pump intake, the well may begin to produce sand. If you notice sand in the toilet tank, the well is in danger of going dry and the pump will likely be damaged.
- **Watch for milky water:** Water that appears milky at first and then clears after standing can be caused by the pump drawing air and may indicate that the water level has dropped.
- **Consider lowering the pump:** Depending on the depth of the well, lowering the pump may be an option. Check with a licensed pump installer.
- **Have the water tested:** As the water table drops and pulls air into the aquifer, the chemistry of the water will change. Sometimes exposing the aquifer to oxygen causes an increase in arsenic concentrations. Send water samples to a lab for testing regularly during and after a drought. The concentrations of other materials and contaminants may also change.
- **Reduce pumping rate and increase storage capacity:** Lowered pumping rates and increased storage capacity may protect your water supply equipment and groundwater resource.
- **Schedule water use:** Work with your neighbors to schedule common or heavy water use. For example, if everyone in a neighborhood typically

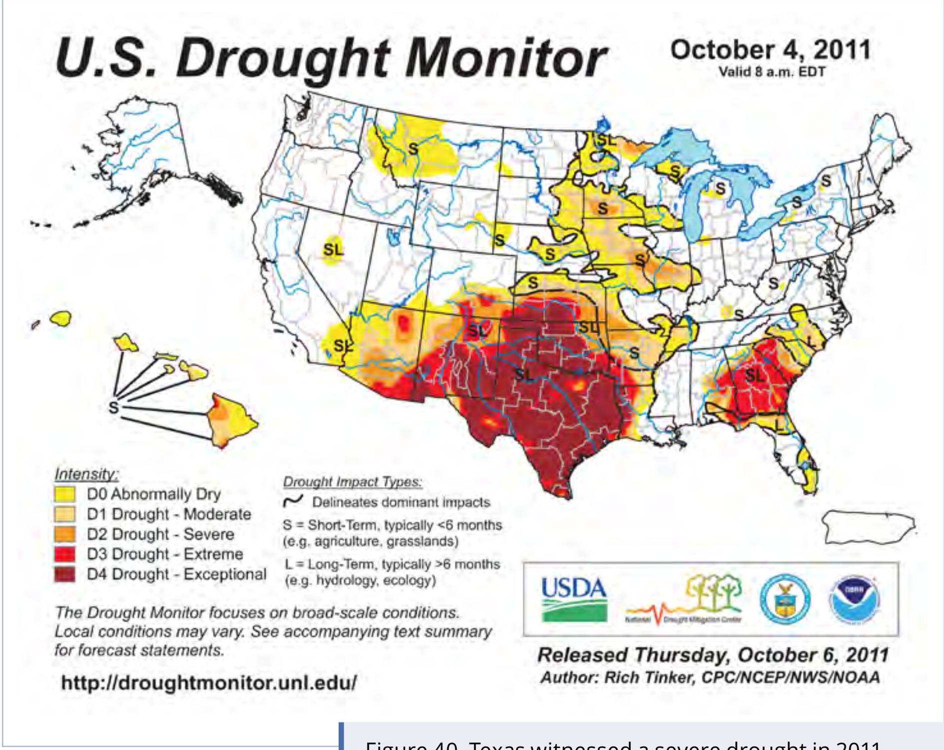


Figure 40. Texas witnessed a severe drought in 2011.

Figure 41. Park well for the Texas Land & Development Co. office in Plainview, Texas (circa 1910).

washes laundry on Saturday, the wells may begin to go dry Sunday. Distribute heavy water use over the week to allow individual wells to recover and sustain the water supply in your neighborhood.

- **Conserve water:** For tips on saving water in the kitchen, bathroom, laundry room, and outdoors, see *http://savetexaswater.tamu.edu*.

References

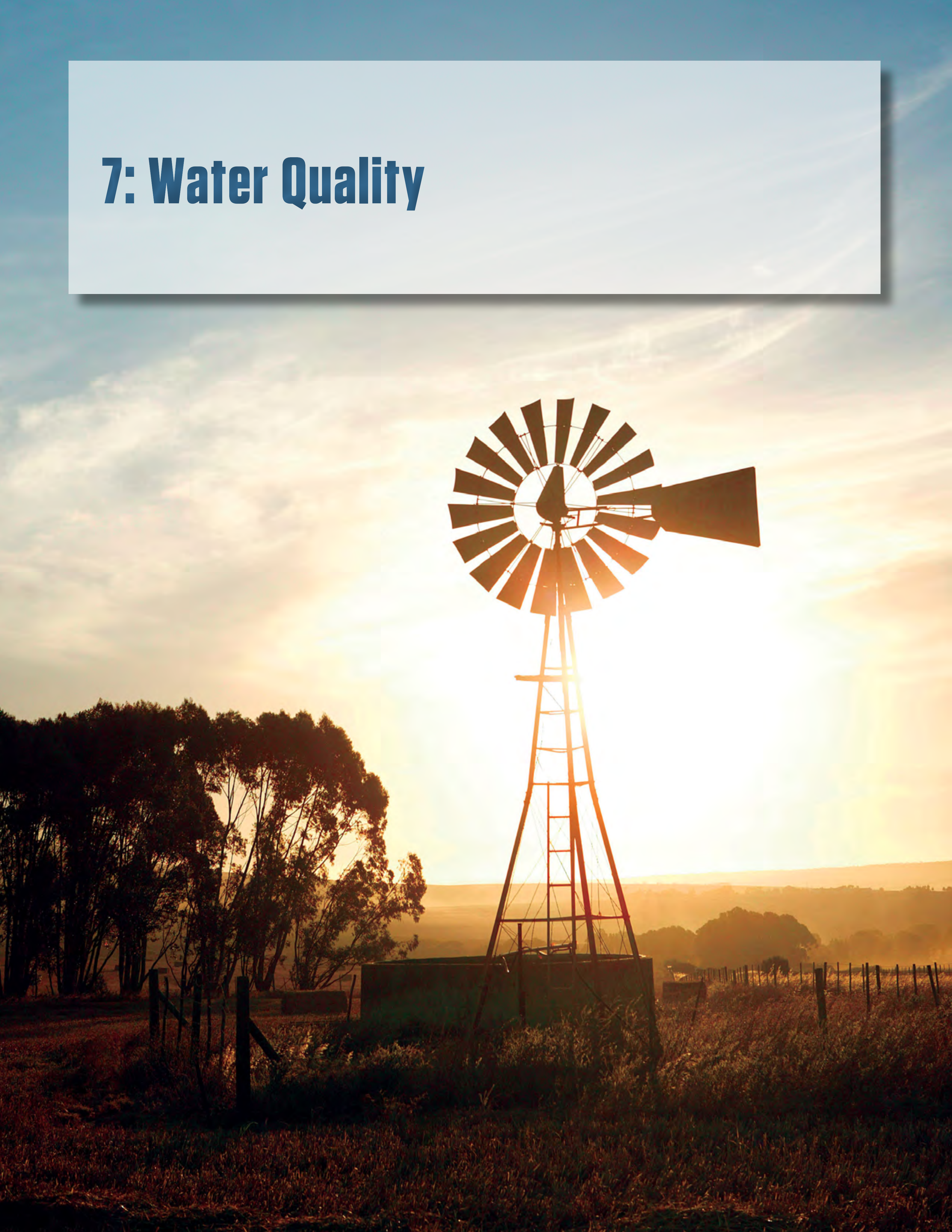
Fipps, G., 2002. *Managing Texas Groundwater Resources through Groundwater Conservation Districts.* B-1612, 2-02. Texas A&M AgriLife Extension Service.

Johnson Division, 1972. *Groundwater and Wells.* Second Printing, Edward E. Johnson, Inc. Universal Oil Products Co., Saint Paul, MN.

Uhlman, K. 2008. *Arsenic in Arizona Ground Water: Source and Transport Characteristics.* University of Arizona Cooperative Extension. *https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1453.pdf.*

Notes

7: Water Quality



As water evaporates and condenses to form rain or snow, it undergoes a natural distillation process that creates "fresh water" to recharge aquifers and support stream flow. Although rainwater is initially pure as it is formed, it can become contaminated by interacting with pollutants in the air.

In its liquid form, water interacts with the environment to dissolve minerals and other substances. It can then transport pollutants and microorganisms into creeks, lakes, and other water bodies, as well as into the ground. Because water can dissolve and transport contaminants, the composition and quality of groundwater or surface water can change over time.

Drinking Water Guidelines and Standards

The Safe Drinking Water Act requires that public drinking water supplies be monitored to make sure that the water is safe and meets federal drinking water standards (*water.epa.gov/lawsregs/rulesregs/sdwa/*); any entity that sells water to the consumer must meet these standards.

Private water well owners should also have their water tested and compare the results against the federal standards.

The U.S. Environmental Protection Agency (EPA) sets the quality standards for drinking water (Fig. 42). The agency evaluates substances to determine whether they should be listed as contaminants in the National Primary Drinking Water Standards.

DID YOU KNOW?

Water shapes the landscape. Flowing water in streams erodes, transports, and deposits sediment. Water participates in both the dissolution and formation of the earth's materials.

The EPA considers many factors when making these determinations, including research results, the costs of treating the water, potential health effects, level of human exposure, the extent of the contaminant in the environment, and the technologies available for detecting and removing the contaminant.

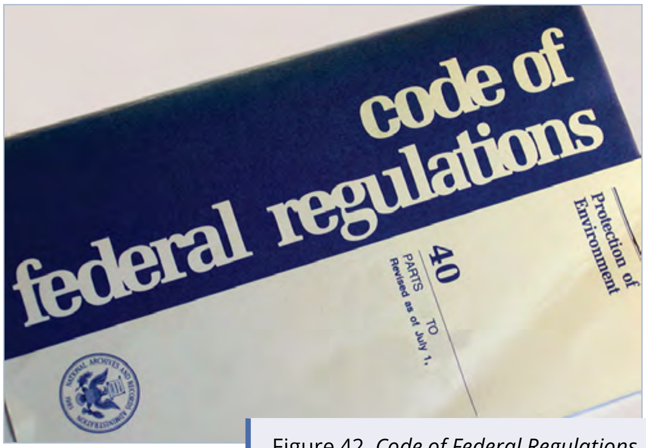


Figure 42. *Code of Federal Regulations, Title 40, Protection of the Environment.*

Two categories of drinking water standards are set: primary and secondary.

Primary drinking water standards apply to substances that pose risks to human health. For each of these substances, the agency sets a maximum contaminant level (MCL) to indicate the dangers of being exposed to it over a lifetime. The MCL list does not include contaminants that would harm a person after one-time or short-term consumption.

If your well water exceeds the MCL for any listed contaminant, it may be unhealthy for consumers. Either find another drinking water supply, or have the water treated to remove the contaminant or reduce its level below the MCL.

For a list of primary contaminants, see Appendix B or the EPA website at (*water.epa.gov/drink/contaminants/index.cfm*).

Secondary standards are set only for aesthetic considerations, such as taste, color, and odor. The EPA has set secondary standards (SMCLs) for 15 contaminants (Table 1). You can drink water that exceeds the SMCL without a health concern, but it may taste, look, or smell bad.

Copper and fluoride have primary as well as secondary standards, which indicate that the water is likely to taste bad before it becomes unhealthy to drink. If your water exceeds the SMCL for any contaminant in Table 1, consider treating the water.

Chemical concentrations are reported in milligrams per liter (mg/L), also known as *parts per million.*

Table 1. National Secondary Drinking Water Standards, and the Primary Standard for copper and fluoride (See Appendix B for the Primary Drinking Water Standards)

Contaminant	Secondary Standard	Primary Standard
Aluminum	0.05–0.2 mg/L	
Chloride	250 mg/L	
Color	15 color units	
Copper	1.0 mg/L	MCL=1.3 mg/L
Corrosivity	Noncorrosive	
Fluoride	2.0 mg/L	MCL=4.0 mg/L
Foaming agents	0.5 mg/L	
Iron	0.3 mg/L	
Manganese	0.05 mg/L	
Odor	3 threshold odor number	
pH	6.5–8.5	
Silver	0.10 mg/L	
Sulfate	250 mg/L	
Total dissolved solids	500 mg/L	
Zinc	5 mg/L	

Total Dissolved Solids

The level of dissolved minerals—including salts, metals, cations, and anions—in water is known as *total dissolved solids* (TDS). TDS is reported in a single value, typically mg/L. Dissolved components in water are usually bicarbonate, boron, calcium, chloride, magnesium, potassium, sodium, and sulfate.

Drinking water with more than 500 mg/L total dissolved solids is not necessarily unsafe to drink, but it may taste salty or stain laundry or plumbing fixtures. TDS is often referred to as a measure of salinity because the most common mineral in high-TDS water in Texas is sodium chloride, or table salt.

Water in Texas has a high salt content because about 200 million years ago, the climate was very hot and arid, and the water in the Gulf of Mexico evaporated, leaving behind layers of salt nearly a mile thick. This evaporite deposit (so named because it consists of minerals evaporated from water) lies under most of the Gulf Coastal Plains and contributes to high TDS values in Gulf Coast aquifers.

In the Basin and Range Province aquifers, an ancient drainage system that could not discharge to the sea produced lakes like the Great Salt Lake in Utah and large inland playas, which are dry, barren areas in the lowest part of an undrained desert basin.

These areas contain concentrated salts that were left when the water evaporated. They often contain high levels of boron, calcium sulfate (gypsum), selenium, and sodium chloride and have high TDS values.

Saline water can stunt the growth of crops and landscape plants. If your water has a high saline content, have it tested to determine the specific combination of minerals in the water supply. Then match the treatment method to the minerals in the water. If the water is used for irrigating crops and landscape plants, have it tested for each mineral to select the appropriate salt-tolerant plant species.

The mineral composition of water may affect its taste. For example, water with a TDS of 500 mg/L composed primarily of table salt (NaCl) feels slippery, tastes slightly salty, and is called soft water. Water with the same TDS value but having roughly equal proportions of table salt, gypsum, and calcite (calcium carbonate) tastes less salty and feels less slippery because of its greater water hardness.

Hardness

Hardness is a measurement of calcium, magnesium, and other minerals in water. Hard water requires more soap for laundry and washing and causes scale to build up in dishwashers, washing machines, water heaters, and plumbing fixtures.

The groundwater from karst limestone aquifers is typically hard because of the calcium and magnesium dissolved from the consolidated rock.

There are no primary or secondary standards for water hardness. The National Research Council states that drinking hard water generally contributes a small amount toward the total dietary needs for calcium and magnesium.

The hardness of water is reported using one of three types of measurements: grains per gallon, milligrams per liter, or parts per million (Table 2).

Table 2. Water hardness scale

Grains per gallon	Milligrams per liter (mg/L) or parts per million (ppm)	Classification
Less than 1.0	Less than 17.1	Soft
1.0–3.5	17.1–60	Slightly hard
3.5–7.0	60–120	Moderately hard
7.0–10.5	120–180	Hard
Over 10.5	Over 180	Very hard

Acidic or Alkaline Water: pH

The pH of water is a measure of how acidic or alkaline the water is, on a scale of 0 (very acidic) to 14 (very alkaline or basic; Fig. 43). A reading of 7 (neutral) represents the pH of distilled water.

In a limestone aquifer, slightly acidic groundwater can slowly dissolve the rock to form caverns and open access to aquifers. The pH of water can contribute to pipe corrosion and some taste problems.

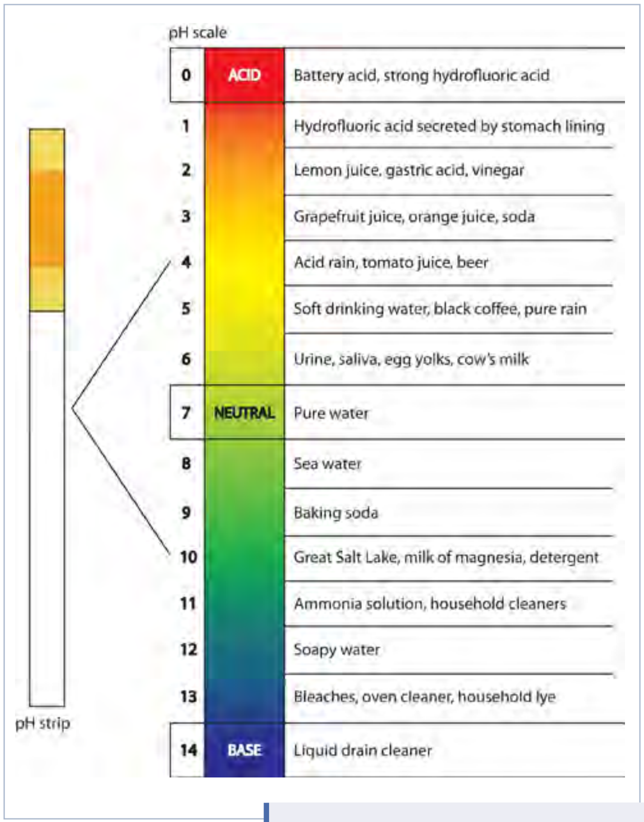


Figure 43. A pH strip and pH scale.

Gulf Coast aquifers can have very acidic groundwater, which can form when oxygen and water come in contact with pyrite (iron sulfide). In the presence of pyrite, groundwater with high concentrations of oxygen can create sulfuric acid. This process, also known as *acid rock drainage,* can dissolve enough of other minerals such as lead, copper, and zinc to make the water toxic.

Organic Matter and Hydrogen Sulfide (Rotten Egg Odor)

Water color and odor are caused by natural organic matter (matter derived from living or once-living organisms) that is often found in surface water but seldom in groundwater. If well water contains organic matter, it is usually derived from vegetation such as leaves falling or roots growing into the well. These constituents can impart taste and color to the water, like when tea leaves are brewed.

The decay of organic matter may generate hydrogen sulfide gas, which smells like rotten eggs. Although colorless, hydrogen sulfide is perceptible by the human nose at concentrations as low as 0.00047 ppm. The gas may corrode pipes as well as stain silverware and plumbing fixtures black.

In aquifers containing pyrite, bacteria can convert the mineral to hydrogen sulfide gas; the bacteria may also generate slime, which promotes the growth of other bacteria and clogs wells and plumbing. Bacteria thrive in the low-oxygen environments of slow-moving groundwater and in warm storage tanks such as water heaters and water softeners.

Another source of hydrogen sulfide gas is a water heater with an electric anode made of magnesium. The magnesium reacts with the sulfate in the water. If you detect the rotten egg odor from hot- but not cold-water faucets, the source is likely the water heater.

DID YOU KNOW?

Water has unique physical and chemical properties. The manner in which water absorbs and releases heat, reflects sunlight, expands upon freezing, and dissolves other materials is essential to life on earth.

To reduce gas production, a licensed plumber can replace the magnesium anode with a zinc anode, but the change may void the warranty. See Chapter 10 for water treatment options to remove hydrogen sulfide gas and sulfur-reducing bacteria.

Dissolved Metals, Iron, and Manganese

The secondary contaminants aluminum, iron, manganese, silver, and zinc, and the primary contaminants copper and fluoride are common elements of the earth that can be dissolved by groundwater.

- Iron and manganese can give water an unpleasant taste, odor, and color.
- Very small particles of iron that do not settle, called colloidal iron, turn the water reddish.
- Iron causes reddish brown stains on concrete, glassware, laundry, porcelain, sinks, and plumbing fixtures. Manganese causes brownish black stains on the same materials. Detergents do not remove these stains. Chlorine bleach may even intensify the stains.
- Manganese usually dissolves clear in water, but some colloidal manganese may tint the water black.
- Water with high concentrations of iron and manganese often contains naturally occurring iron or manganese bacteria. These bacteria feed on the minerals in the groundwater and form a reddish brown (iron) or brownish black (manganese) slime in toilet tanks and can clog water systems.
- Well water with iron and/or manganese concentrations may be clear when it is drawn from the tap, but particles may soon form and settle at the bottom of the container once the water is exposed to air.
- Inappropriate levels of copper, fluoride, and other metals can harm human health (see Appendix B).

Naturally Occurring Contaminants in Texas Groundwater

Besides TDS, there are four naturally occurring contaminants that most often exceed the primary drinking water standards in Texas groundwater. They are arsenic, fluoride, radionuclides, and uranium.

Arsenic

Arsenic is found in nearly all physiographic provinces of Texas. Concentrations above 20 parts per billion (ppb) are found in the Ogallala Aquifer of the High Plains, the Gulf Coastal Plains, and the Basin and Range.

Arsenic is a human health concern: it causes problems in the skin and circulatory system, and it may increase the risk of cancer. Consuming water with concentrations above the MCL of 10 ppb (0.010 mg/L) can harm people and animals.

The arsenic in the Ogallala Aquifer originated in the Rocky Mountains, where magma pushed upward and hardened into granite and into veins containing copper, silver, gold, and arsenic. The Central Texas Uplift and Llano aquifers also have veins containing gold and arsenic.

Arsenic becomes soluble in water in specific chemical forms and at certain water pH levels and oxygen contents. Any change in an aquifer’s chemistry may raise or lower its arsenic concentrations.

For example, oxygen can be introduced into an aquifer as groundwater elevations drop during drought. In Arizona, livestock were killed by arsenic poisoning after the geochemistry of the Basin Fill aquifer changed, raising the arsenic concentrations in the water.

Fluoride

Fluoride is a common mineral that is concentrated in volcanic materials; it dissolves naturally in groundwater of confined aquifers. In Texas, the highest fluoride concentrations are in the confined aquifers of the Gulf Coastal Plains.

An extreme example of groundwater containing naturally occurring dissolved fluoride is in South Carolina, where fluoride is dissolving out of fossil shark teeth that were deposited in an unconsolidated coastal aquifer.

DID YOU KNOW?

Fresh water is less than 3 percent of the water at the earth's surface. Most fresh water is stored as glaciers and less than 1 percent of the earth's water near the surface is drinkable. About 99 percent of this water is in the form of groundwater.

Although it can be harmful at high concentrations, fluoride is essential for strong teeth and bones. Many municipal water supply systems add fluoride to the water to support dental health. Excessive fluoride concentrations in drinking water can discolor teeth. The maximum contaminant level for fluoride is 4.0 mg/L.

Radionuclides and Uranium

Radioactivity is the release of energy from within atoms. Some atomic structures are inherently unstable and spontaneously break down (radioactive decay) to form more stable atoms.

For example, the potassium 40 isotope decays very slowly (half-life of 1.25 billion years) but eventually becomes the element argon. Because potassium is a significant component of clay minerals, it is generally true that everything containing potassium—including animals, plants, clay soils, and bricks and pottery made of clay—is slightly radioactive.

Any element that decays by emitting radioactive particles is known as a *radionuclide.* As radionuclides decay, they produce daughter products (such as potassium to argon) that are shorter lived and possibly more radioactive. Of particular concern in Texas are naturally occurring uranium and radium, which can accumulate to harmful levels in drinking water.

As radionuclides decay, they emit radioactive alpha particles, beta particles, and gamma rays. Each type of particle affects humans differently.

Alpha particles are the least penetrating type of radioactive particles; they can be stopped by a sheet of paper or the skin. However, they are still harmful if inhaled or ingested, because then they come into contact with internal organs.

The MCL for gross alpha radiation is 15 picocuries per liter, (pCi/L, a measurement of the intensity of radioactivity). Several Texas aquifers have been found to contain alpha particle radiation exceeding the MCL, including the Ogallala, the Gulf Coastal Plains aquifers, and the Edwards Plateau.

Beta particles can be stopped by a piece of wood or a thin sheet of metal such as aluminum foil. The MCL for gross beta activity is 50 pCi/L.

Concentrations greater than 50 pCi/L have been found in scattered locations across the Gulf Coastal Plains aquifers, the Edwards Plateau, the Ogallala, and the Basin and Range.

Gamma rays, like x-rays, can pass through the human body and are best shielded by dense materials such as lead or thick concrete. Fortunately, they are seldom detected in Texas aquifers.

Figure 44. Flowing artesian well in Dimmit County, Texas (circa 1910).

The most common sources of radioactivity in Texas are dissolved uranium and dissolved radon gas. Uranium is a common element on earth and is present in granite and sandstones. Black shale was formed where the low-oxygen environment of deep ocean muds pulled dissolved uranium from the ocean water, concentrating and immobilizing the element in shale.

Uranium (half-life of 760 million years) is unstable and eventually becomes a new element, radium (half-life of 1,620 years), which then decays to the element radon (half-life of 3.8 days).

Radon is strongly radioactive and emits high-energy alpha particles. It is a colorless, odorless, tasteless gas that dissolves in groundwater and may migrate upward through the soil, eventually dissipating into the atmosphere.

If radon gas is trapped within a structure, such as a basement or well house, the concentration of radon gas within the closed structure may exceed health standards.

Radon is considered the second leading cause of lung cancer in the United States. The EPA estimates that one in 15 U.S. homes contains high levels of the gas (*www.epa.gov/rado/radontest.html*). The MCL for radon gas is 300 pCi/L.

References

Lesikar, B. J., R. H. Melton, M. F. Hare, J. Hopkins, and M. C. Dozier. 2006. *Drinking Water Problems: Radionuclides.* Texas A&M AgriLife Extension Service.

National Research Council. 1980. *Drinking Water and Health, Volume 3,* National Academy Press, Washington, DC.

Zack, A. L., 1980. *Geochemistry of Fluoride in the Black Creek Aquifer System of Horry and Georgetown Counties, South Carolina—and its Physiological Implications.* U.S. Geological Survey Water Supply Paper 2067. Reston, VA.

Notes

8: Common Contaminants in Well Water

A recent study by the U.S. Geological Survey found that more than 20 percent of the private household wells tested contained one or more contaminants at a concentration greater than what is recommended by the EPA.

The contaminants found most often were inorganic and occurred naturally, such as arsenic and radon. The most common human-made contaminant at unsafe levels was nitrate. Microbial contaminants were detected in as many as one-third of the sampled wells.

Nitrate

As in the rest of the nation, the most common pollutant derived from manufactured sources in Texas is nitrate. Because nitrate is colorless, odorless, and tasteless, it is undetectable without testing.

Nitrate contamination may be a concern in areas where excessive amounts of agricultural fertilizers have been applied and in areas that are served by individual septic systems and domestic wells.

Other possible sources of nitrate include municipal waste and animal waste. In rural areas, nitrate is commonly discharged from septic systems, which can pollute surface water and groundwater (Fig. 45). Even if they have been designed properly and are operating efficiently, traditional septic tank/drain field systems can discharge enough nitrate to exceed drinking water standards.

Nitrate concentrations in water are reported as nitrate-nitrogen or total nitrate. Ten mg/L of nitrate-nitrogen is equal to 44.3 mg/L nitrate.

The maximum contaminant level for nitrate-nitrogen is 10 mg/L because of its acute health effects (those resulting from ingestion of a contaminant over a short period). The specific nitrate-nitrogen risk is for methemoglobinemia, or "blue baby syndrome," in which the blood cannot carry enough oxygen to the individual cells in the body.

Although high concentrations of nitrate in groundwater are usually caused by human activities, low concentrations of it can occur naturally in arid soils.

Bacteria and Pathogens

About half of the waterborne disease outbreaks documented in the U.S. every year are caused by drinking water supplies that depend on groundwater.

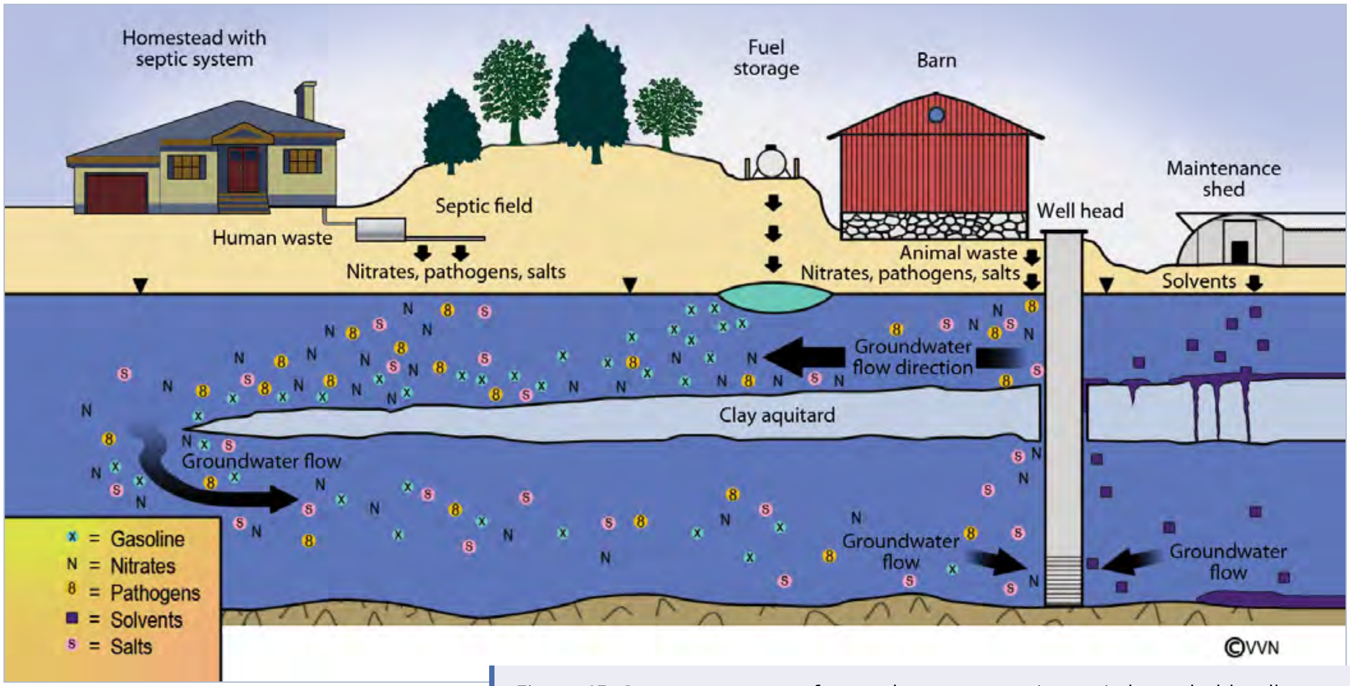


Figure 45. Common sources of groundwater contaminants in household well water.

Disease-causing organisms are known as *pathogens.* Enteric (intestinal) pathogens are common in groundwater. If these and other specific organisms are detected in water, it may be contaminated with fecal matter (human waste).

These pathogens can originate from leaking sewer lines, septic systems, and improperly protected wellheads. Organisms of particular concern in groundwater include:

- Viruses such as adenoviruses, rotavirus, hepatitis A, and norovirus
- Bacteria such as *E. coli* 0157:H7 (Fig. 46), *Salmonella, Campylobacter, Pseudomonas, Helicobacter, Aeromonas, Vibrio cholerae,* and *Shigella*
- Protozoans such as *Cryptosporidium* and *Giardia*
- The recently reported amoeba *Naegleria fowleri*

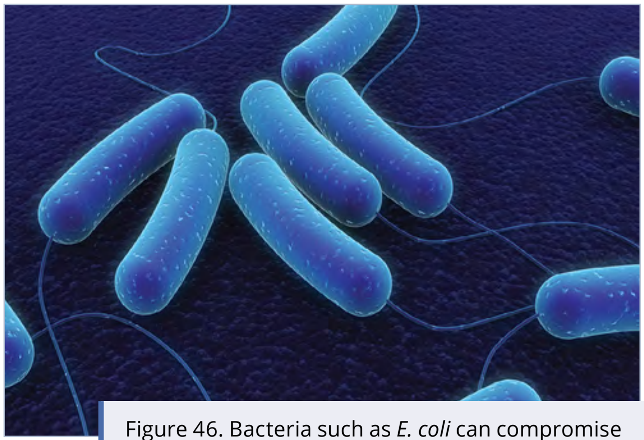


Figure 46. Bacteria such as *E. coli* can compromise human health and can indicate that other contaminants may also be present in groundwater.

People who consume water containing these organisms can suffer abdominal pain, acute gastroenteritis, dehydration, diarrhea, and severe cramping.

The amoeba *Naegleria fowleri* has been found in domestic wells and other drinking water systems that use groundwater. According to the U.S. Centers for Disease Control, the amoeba enters the body through the nose, travels to the brain and spinal cord, and destroys brain tissue.

Infections can occur when people are immersed in warm freshwater or untreated groundwater, such as when swimming or diving. Some people have been infected while water skiing in warm freshwater lakes.

Because *Naegleria* is commonly found in warmer climates, it is more likely to be in states across the South. Although it is found in wells and hot springs across the South and Southwest, infections occur only by immersion in the water and not as a result of drinking contaminated water.

Some bacteria form biofilms in wells that contain enough nutrients, such as nitrate, for survival (Fig. 47). Biofilms can develop after biodegradable oils are used to lubricate pumps and in the high groundwater temperatures in some parts of Texas. Bacteria and other organisms, such as *Naegleria,* may feed on the bacteria in wells and water storage tanks.

Although all of the above-mentioned organisms can make people sick, viruses (Fig. 48) are often considered more of a threat to groundwater than are bacteria or protozoans. Because they are tiny, viruses can be transported farther into the aquifer and are thought to be able to survive longer in the environment than can bacteria.

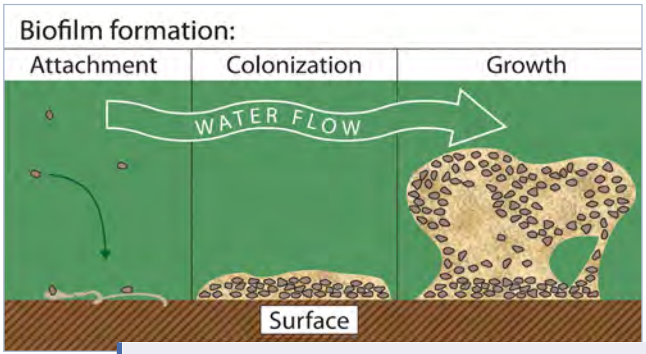


Figure 47. Biofilms form from slime bacteria that feed on iron, manganese, and/or nitrate.

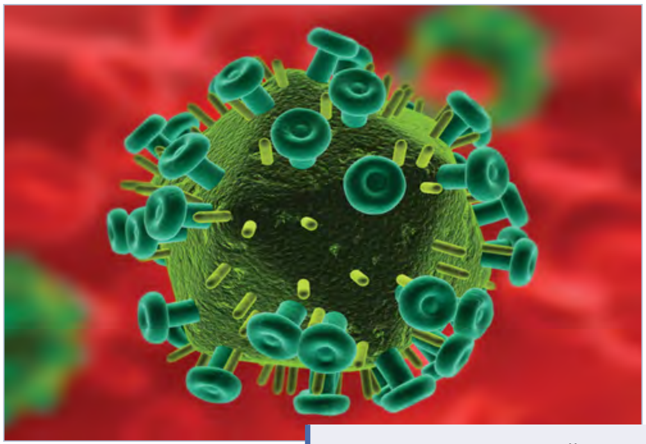


Figure 48. Viruses in well water can cause human illness.

A study of public drinking water utilities across the United States found that about one-third of the groundwater-based systems contained viruses that cause diseases in people.

Contaminants Produced by People

The chemicals that have been introduced into the environment by human activity are known as *anthropogenic* contaminants. These pollutants include chemicals made by industry, those derived from the oils and grease flushed off roadways, and chemicals applied to crops, landscape areas, and yards.

Water contaminants can be found very close to home. For example, after a tank of aquarium fish died in Arizona, the cause was traced to mercury in the water supply. The single source of mercury was a broken switch in one of the neighborhood's water wells.

In a new subdivision in New York, a group of private domestic wells was tested for contaminants after residents expressed concern about a nearby landfill. All the wells failed water quality tests when a dissolved industrial solvent was found in the water.

Because the solvent is a common contaminant in landfills, authorities conducted an extensive investigation, but no link to the landfill could be found. The source of the contamination turned out to be the solvent used to glue PVC pipes in the wells and plumbing.

Contaminants can be released into the environment by chemical plants, gas stations, landfills, manufacturing facilities, mining activities, and repair shops. Many EPA Superfund sites (abandoned toxic waste dumps) were first discovered because domestic well owners noticed that their household well water had an odd taste or unusual odor.

In some cases, plumes (columns of one fluid moving through another) of groundwater contamination extend miles beyond their original source. The contaminant is diluted with distance as the plume dissipates, mixes with uncontaminated water, and moves down gradient.

Superfund sites are listed at *www.epa.gov/superfund/*. If a site is in your neighborhood, consider checking with the Texas Commission on Environmental Quality for information about your water supply and its risks of contamination.

In the late 1970s, the gasoline additive methyl tertiary-butyl ether (MTBE) was added to gasoline to boost octane, replace the toxic metal lead, and reduce air pollution. Unfortunately, this chemical was not tested fully before being approved as a gasoline additive, and it was later tied to respiratory problems.

The chemical has since been found to be very soluble and stable (it biodegrades very slowly). It has contaminated many groundwater supplies after having leaked from underground gasoline tanks (Fig. 49). MTBE is now banned or partially banned in many states, and additional actions are being taken to reduce and eventually eliminate its use.

For a domestic well, the source of groundwater pollution is most likely to be near the wellhead. The most common sources are livestock, dog pens, failing septic systems, and stored pesticides, fertilizers, oil, and grease.

Figure 49. Leaking underground gasoline storage tanks are a common source of groundwater contamination.

To protect groundwater, the wellhead must be built and maintained properly, and potential contaminant sources nearby must be managed well. Many states ban septic tank degreasers because the chemicals percolate rapidly through soils and contaminate aquifers.

Sometimes the odor of well water can alert us to the presence of contamination. However, do not rely solely on the water's smell or taste to determine whether it may be contaminated.

Emerging Contaminants

The EPA is continually evaluating substances that may need to be regulated in community water systems. Called emerging contaminants, these include chemicals that new techniques enable us to measure at very small concentrations. The new methods may reveal the presence of common household chemicals that were not expected to end up in groundwater.

Newer findings of contaminants in water include very small concentrations (parts per billion and parts per trillion) of chemical fire retardants, antibiotics used in household soaps, and chemicals from products containing Teflon, Scotchgard, and Gore-Tex.

Of increasing concern are pharmaceuticals and personal care products, some of which may affect the endocrine systems of living organisms. Pharmaceuticals may be flushed through human bodies and transferred to septic leach fields. According to the EPA, pharmaceuticals and personal care products include cosmetics, diagnostic agents, fragrances, sunscreens, vitamins, and therapeutic and veterinary drugs.

Disinfection by-products are chemical contaminants that form when water disinfection chemicals come in contact with dissolved organic materials in water. These contaminants must be removed from public water supplies that are treated with chlorine. However, unless you add chlorine or bleach to disinfect the well water, these contaminants are unlikely to be found in your water supply.

References

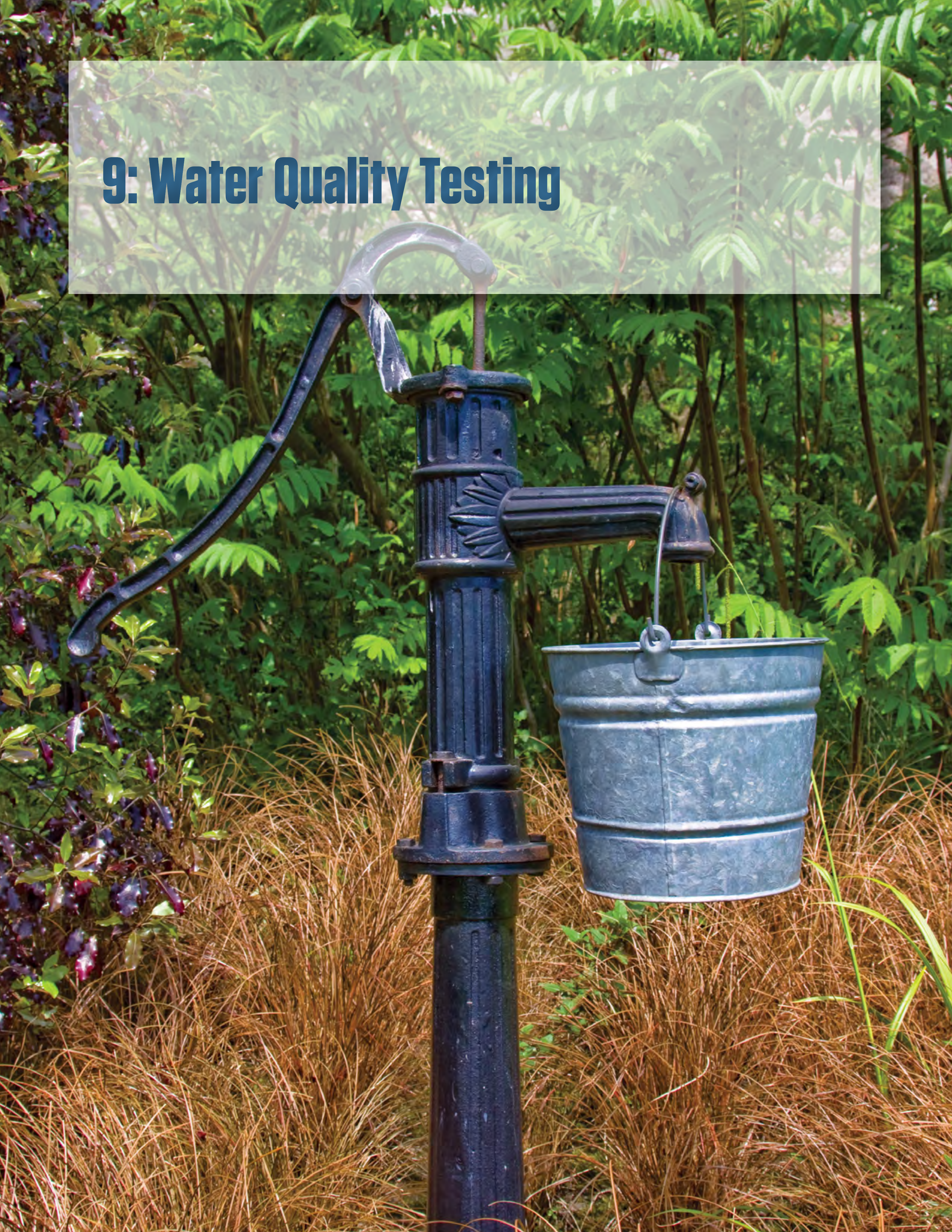
Abbaszadegan, M., M. LeChevallier, and C. P. Gerba. 2003. "Occurrence of Viruses in U.S. Groundwater." *Journal of the American Water Works Association.* 95(9):107–120.

DeSimone, L. A., P. A. Hamilton, and R. J. Gilliom. 2009. "Quality of Ground Water from Private Domestic Wells." National Ground Water Association, *Water Well Journal* summary of USGS Scientific investigation report 2008-5227 *Quality of Water from Domestic Wells in Principal Aquifers of the United States, 1991–2004*

Payal, Sakar. 2008. *Occurrence and Inactivation of Emerging Pathogens in the Environment.* Ph.D. Dissertation. University of Arizona, Tucson, AZ

Notes

9: Water Quality Testing



Because no federal, state, or local entity ensures the safety of private well water, the responsibility for monitoring it falls to the well owner. Compared to people who consume public drinking water, private well owners are more likely to be exposed to unsafe drinking water.

You will need to find out the quality of the water in your aquifer. Some information about the aquifer water may be readily available from public utilities and water companies. They are required by federal and state law to report water chemistry to consumers. Contact the water utility for a copy of the water quality report for information about local water quality issues.

However, water quality information on exempt household wells is not recorded or made available through any public agency unless the well owner has given permission.

Have your water tested whenever:

- You suspect it may be contaminated.
- You notice a change in color, taste, or odor of the water.
- The pump or well has undergone maintenance recently.
- People who drink the water have experienced a change in health, especially stomach-related illnesses.
- If the well water is cloudy or smelly, or tastes bad, it probably does not conform to drinking water quality standards.

Water Quality Testing Schedule

Because it can cost $4,000 or more to analyze water for all EPA-recommended tests, first have it checked only for the contaminants that are most likely to be in your well water. Table 3 provides a list of recommended tests and frequency of testing.

Initial tests should be conducted when a new well is installed. Some lending institutions may require the well water to be tested before authorizing a loan; however, the tests may be limited to bacteria and would not determine whether a water treatment system should be installed.

Appendix C lists symptoms related to poor water quality, tests, and possible causes.

If oil or gas exploration and development are occurring in your area, consider having your well water tested. In these situations, measure the baseline chemistry of the water to establish its current quality, so that any changes can be detected and verified.

The aquifer may already contain contaminants that occur naturally in normal geologic processes. Also, small amounts of petroleum constituents and natural gas may have seeped up toward the surface from reservoirs deep underground. Trace concentrations of these contaminants may be present naturally before any hydraulic fracturing operation is conducted.

Table 3. Recommended testing schedule for well water

Frequency	Action
Initial[1]	For baseline water quality testing, analyze for arsenic, chloride, fluoride, hardness, iron, manganese, nitrate, pH, radionuclides, sodium, sulfate, total coliform bacteria, total dissolved solids (TDS), and uranium. In aquifers with elevated TDS, consider adding boron and selenium to the baseline testing.
Annually	Test for total coliform bacteria and nitrate. Although TDS is not expected to change in an aquifer, monitoring TDS annually for any trends could provide helpful information.
Monthly	Look for and note changes in: Turbidity (cloudiness, particulates) Color, odor, and taste[2] Health changes (recurring gastrointestinal problems in children and/or guests)

[1] Annual testing may not be needed for these chemicals because they usually occur naturally and their concentrations do not change over time.
[2] Consider repeating one or more of the initial tests after reviewing Appendix C to identify possible sources of these problems.

In addition to annual testing for coliform bacteria, nitrate, and total dissolved solids, have the water screened for non-refined hydrocarbons also to establish whether it contains constituents related to oil and gas development.

Consider testing water wells that are near natural gas or oil development wells for the constituents in Table 4. By stipulating the recommended testing method, you will be assured that the laboratory uses the appropriate standard method.

Table 4. Recommended baseline testing for domestic wells in areas of oil and gas exploration and development

Constituent	Laboratory method	Estimated cost
Dissolved methane	RSK-175 or 176	$75.00
Total dissolved solids (TDS)	SM 2540C	$20.00
Total petroleum hydrocarbons (TPH)	TX-1005 or 1006	$60.00

All groundwater typically contains some solids that occur naturally. TDS is most often correlated with the dissolved salts of sodium, potassium, calcium, and magnesium.

The TDS of groundwater usually ranges from 150 to 400 mg/L, but it is considerably higher in water from some Texas aquifers. If the baseline value for total dissolved solids exceeds the EPA secondary drinking water standard of 500 mg/L, test the well water again to pinpoint the specific dissolved minerals.

For example, bromide is common to brackish water and brines that may be associated with ocean water or with oil exploration. Any change in TDS from baseline is of concern because it suggests groundwater contamination that may—or may not—be caused by oil or gas development.

Although dissolved methane and hydrocarbons are not expected to be in groundwater, they may be present naturally if the aquifer is near an oil- and gas-producing zone. Methane may be associated with coal beds. If these constituents are found in the baseline test, consult a water treatment professional and order further testing as recommended.

After hydraulic fracturing or any oil/gas development activity, retest the water to compare it against the baseline. If the water quality has changed significantly since the baseline test, have a water treatment professional investigate further. Any change in water color, odor, or taste also calls for additional water quality tests.

The EPA fields questions about drinking water quality on weekdays from 7:30 a.m. to 3:30 p.m. Central Time. Call the Safe Drinking Water Hotline at 800-426-4791.

To find a laboratory, contact your county health department or select from a list of laboratories certified by the National Environmental Laboratory Accreditation Conference Institute at *lams.nelac-institute.org/*.

To find a water treatment professional, ask a local licensed well driller, pump installer, or plumber, or search TCEQ-licensed water treatment specialists through the Group Search Criteria at *https://www2.tceq.texas.gov/lic_dpa/index.cfm?fuseaction=licall.searchgp*. Water quality questions may also be directed to the local groundwater conservation district (see Chapter 6).

How to Sample a Drinking Water Well

When a new well is installed, a water sample should be tested for the presence of bacteria. Collect samples at the wellhead before connecting the new well to household plumbing. Most drillers install a tap or spigot near the wellhead to facilitate sampling.

For an existing well, test the water from the faucet where drinking water is obtained. This sample will represent the quality of the drinking water *after* the water has passed through the existing storage, treatment, and plumbing systems. If the water is safe for drinking, repeat the tests annually.

If the test indicates a water quality problem, purge the well and plumbing system. Run water from the sample collection spigot until all standing water has been flushed and water is coming directly from the aquifer. For a typical domestic well, purging can be achieved by first washing one or two loads of laundry and/or watering the garden, and then letting the faucet run for at least 10 minutes before taking the sample.

After purging, collect a sample at the wellhead or at a point before the water enters any existing treatment system, and have it tested. Compare the results of the initial faucet analysis to those for the wellhead sample. The water quality issue may be the result of the failure of the treatment system, or additional treatment equipment may be necessary.

DID YOU KNOW?

Earth is unique in the solar system in that water has coexisted at its surface in three phases—solid, liquid, and gas—for billions of years, which allowed the development and continuous evolution of life.

Discuss the test results with a water treatment professional to determine the appropriate action. If bacteria are in the well water, treat the well directly with shock chlorination and treat the water within the household using a method from Chapter 10.

Although well owners can collect samples, the analysis should be conducted by a drinking water laboratory certified by the National Environmental Laboratory Accreditation Program. **The lab will provide sample collection bottles and instructions on how to collect, manage, and ship the samples to the lab for analysis. Follow these instructions exactly.**

For example, tests for dissolved methane require that the collection bottle be filled to the top with no air bubble. If an air bubble is left, the dissolved methane could degas from the water during shipment and collect in the air bubble, invalidating the sample analysis.

Interpreting Water Test Results

Certified drinking water laboratories report the test results and compare them to the maximum contamination levels. The measurement units will be either in ml/L (parts per million, ppm) or in µl/L (parts per billion, ppb). Radionuclides are reported in pCi/L (picocuries per liter) or millirems per year.

Compare the results to the MCL standards (Appendix B). Any water quality constituent that exceeds the MCL is a human health concern; have the water treated.

Doing Your Own Testing: Water Testing Kits

Many types of disposable water testing kits are available. Use one that relies on color changes in either a paper strip or a liquid solution; these kits provide color scales to indicate the estimated level of a contaminant based on the color intensity (Fig. 50).

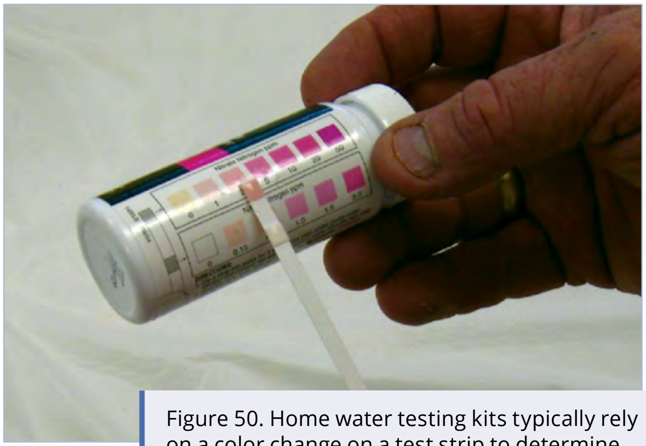


Figure 50. Home water testing kits typically rely on a color change on a test strip to determine the concentration of a contaminant.

The kits provide complete instructions and easy-to-follow steps. If you do not follow the directions exactly, the results will probably be incorrect.

Other kits may provide only a negative or positive result, which will be of limited use if the MCL is more than zero.

Compared to many EPA-approved methods used in certified laboratories, testing kits have several limitations:

- They may detect only the contaminants that exceed drinking water standards.
- The contaminant detection range is limited.
- The procedure or shortcuts used may not be an approved method.
- The results are often inaccurate.
- The results may be influenced by the presence of other water constituents, such as dissolved iron. Dissolved iron often leads to a “false positive” test result on many kits, which indicates that a contaminant is in the water, but it is not really present.

On the other hand, these kits can serve you well when:

- The kit is from reputable company and has been certified or approved by the EPA.
- It is used for routine verification of water quality in conjunction with less frequent analysis conducted by a certified laboratory.
- You need it for peace of mind and to save money and time.
- You want to routinely monitor a well and to notify the well owner when more accurate testing may be required.

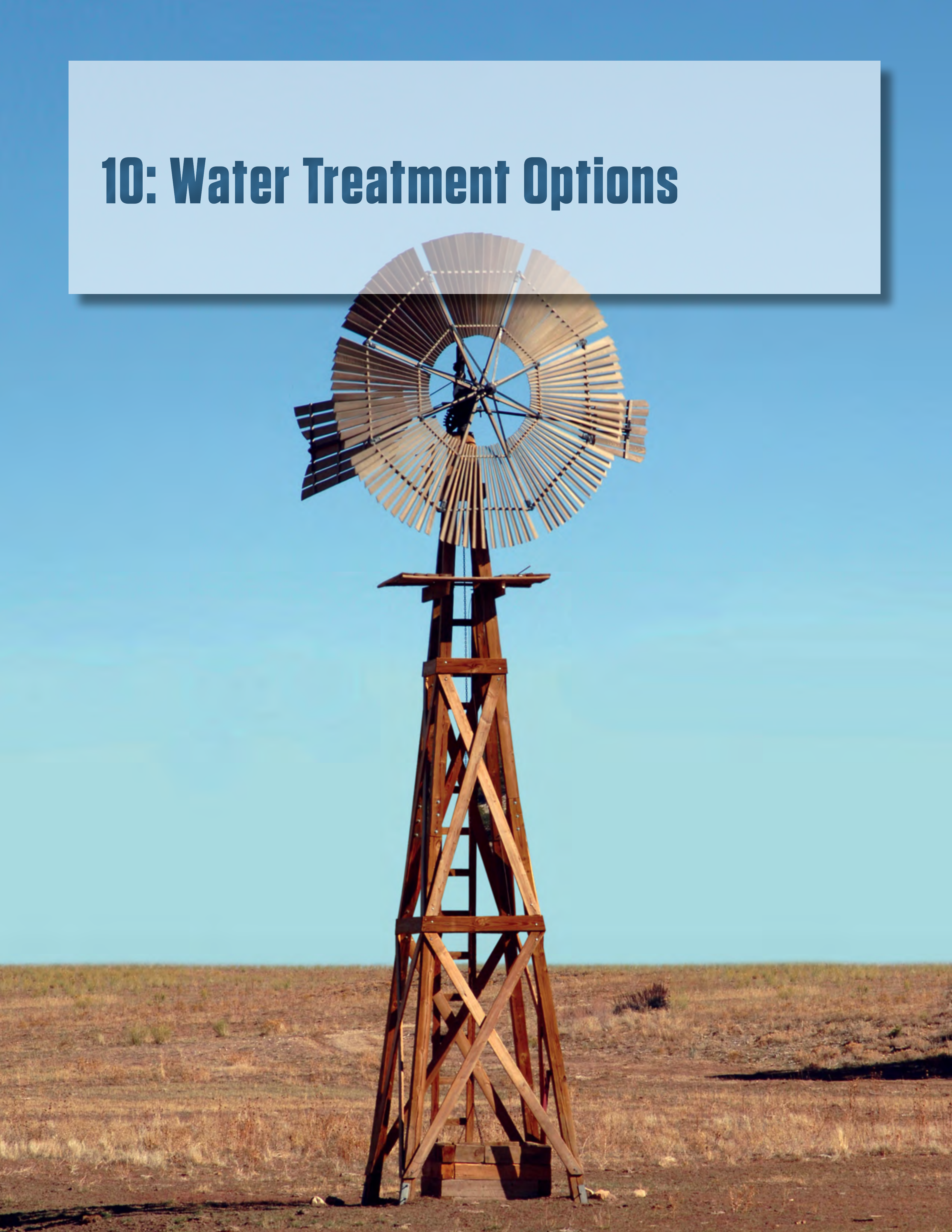
Home testing water analysis kits cost from a few to thousands of dollars, depending on the number of tests, test methods, and the degree of precision and accuracy. Make sure that the procedure is not more complex than you can follow.

Water testing kits are available from independent companies such as EMD Millipore, Hach, Lamotte, and Waterworks, and from resellers such as Ben Meadows (no endorsements implied).

Figure 51. Testing a water well for rice farming near El Campo, Texas (circa 1910).

Notes

10: Water Treatment Options



Although well owners have many options for water treatment systems, choosing one can be difficult. Depending on the amount of water and its degree of contamination, you may need to get professional assistance in selecting and installing well water treatment systems. The selection can be hindered by incomplete or misleading information about costs, treatment options, and water quality.

Experts and regulatory agencies have identified five methods to reduce water contaminants efficiently: disinfection, distillation, filtration, ion exchange, and reverse osmosis.

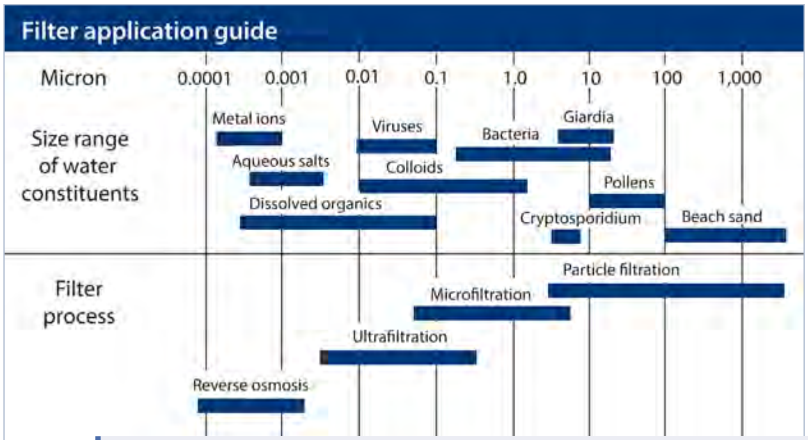


Figure 52. A filtration guide showing the appropriate filter processes according to the particulate size of the water contaminant.
(Modified from U.S. Bureau of Reclamation, Water Quality Improvement Center).

Water treatment systems are categorized according to where they are installed and how much water they can treat:

- A **point-of use-system** is installed at the kitchen faucet or the location where drinking water is most often obtained.
- A **whole-house system** treats water as it enters a home plumbing system.

If you are using more than one treatment system, install the one that removes the larger particles such as sand and grit ahead in sequence of the one that treats the smaller constituents such as salts and viruses (Fig. 52).

Particle and Microfiltration

Particle filtration is a process that removes small amounts of suspended particles—ranging in size from sand to clay—from well water. Filters made of sand or fiber are common (Fig. 52). Filters are made to remove specific particle sizes.

To keep the filter from becoming clogged or overgrown with bacteria, back-flush or replace the media as often as the manufacturer recommends. Filtration can be used alone or prior to other water treatment devices installed in sequence.

Home filters are not intended to filter large amounts of water; however, larger filtration systems—usually whole-house systems or those located near a wellhead—can remove sediments and particulates.

Microfiltration may be used to remove some bacteria and large pathogens such *Giardia* and *Cryptosporidium.*

Figure 53. A simple filtration system.

Filters can be made to react with contaminants. Examples are iron-based media that filter water and absorb arsenic, and activated carbon filters that capture organic chemicals.

Some contaminants cannot be filtered from well water. For water with high concentrations of bacteria and viruses, use chemical disinfection or distillation. Other contaminants can be removed only with reactive media, which are resins or other materials that chemically react with the water as it passes through the filter.

Activated Carbon Filter

Activated carbon filtration, a form of ultrafiltration with a reactive media, is often used as a point of use treatment (Fig. 54). Activated carbon consists of particles of coal or charcoal that react with chemicals passing over its surface.

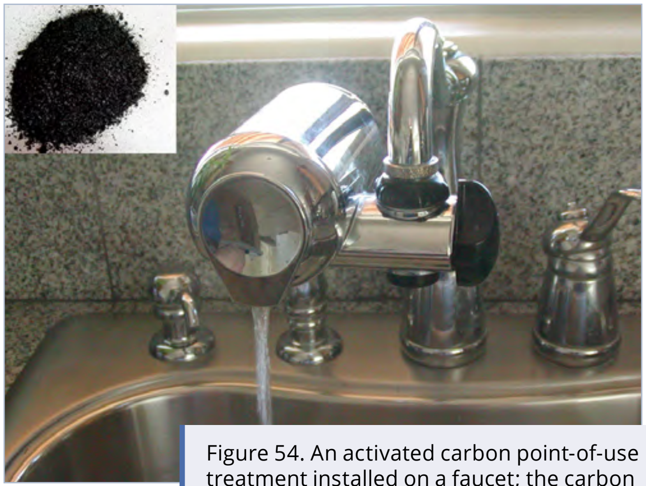


Figure 54. An activated carbon point-of-use treatment installed on a faucet; the carbon media is shown in the photo insert.

The carbon material is processed to increase its porosity; after processing, just 10 grams of activated carbon has a surface area equal to a football field.

Activated carbon filters can remove low concentrations of organic chemicals, such as pesticides and solvents, from drinking water as well as improve its taste and odor. Many chemicals and some dissolved metals will bind to the surface of carbon. Activated carbon may also reduce copper, lead, mercury, and radon gas.

These filters do not reduce inorganic ions such as calcium, chloride, fluoride, nitrate, or sodium. They also will not disinfect or soften (remove hardness) the water.

Although whole-house activated carbon filters can treat large amounts of water, they usually must be installed and maintained by professionals. If the well water is cloudy, install a particle filter in sequence before the activated carbon filter to remove particles that could plug or reduce the efficiency of the activated carbon filter.

If you do not replace the carbon regularly, microbial growth can clog the media and affect the water quality. Always follow the manufacturer's instructions and replace the carbon regularly.

Reverse Osmosis

Reverse osmosis (RO) is becoming a common home treatment method for reducing arsenic and total dissolved solids in drinking water (Fig. 55). Best known for its use in water desalinization projects, this method can also reduce chemical contaminants associated with unwanted color and taste. It may reduce up to 80 percent of pollutants such as arsenic and uranium, and many types of organic chemicals.

Reverse osmosis does not remove dissolved gases such as radon, some pesticides, and volatile organic chemicals such as degreasers and solvents. Check with the manufacturer to determine which contaminants that a specific unit targets and what percentage of the contaminant that it removes.

One drawback of RO treatment is the large amount of brine (salty water) it produces. Depending on the initial concentration of the source water, more than 60 percent of the total amount of water entering the treatment system is discarded as waste. This wastewater brine may overwhelm a septic system and alter the soils in the leach field. The salts may seep underground and possibly enter the groundwater.

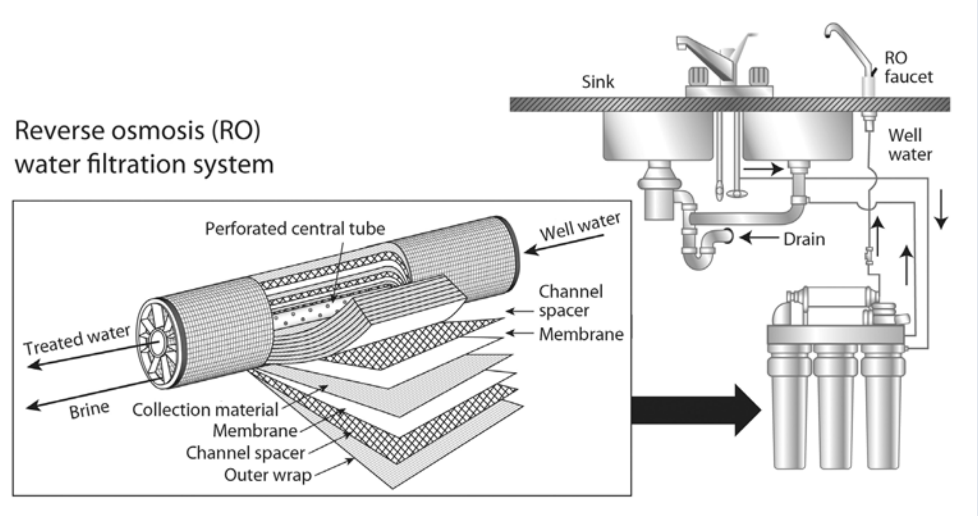


Figure 55. A home reverse-osmosis system.

Reverse osmosis is not recommended for pathogens or sediments (particles). For RO to work best, the water should first be pretreated by particle filtration, activated carbon filtration, chlorination, pH adjustment, or even water softening.

As with all filter systems, the filter must be changed according to the manufacturer's recommended schedule, or microbial growth will clog the system and impair water quality.

Distillation

Distillation removes inorganic contaminants such as minerals and dissolved metals from water. It kills or removes microorganisms, including most pathogens. Although distillation can also remove organic matter, its effectiveness depends on the chemical characteristics of the contaminant.

Beware: Volatile organic chemicals (VOCs) such as benzene and solvents should be removed before the distillation process; otherwise, they may vaporize along with the water and re-contaminate the water.

Some distillation units may initially purge some steam and volatile chemicals. Vent these units properly to prevent indoor air contamination. Some home distillation units use activated carbon filters to remove VOCs during distillation.

Because distilled water has no minerals, it tastes flat or slightly sweet to some people.

Ion Exchange: Water Softening

Ion exchange units are reactive media filters that replace calcium and magnesium ions in water. These units are also known as water softeners (Fig. 56).

Hard water becomes "soft" after the calcium is replaced with either sodium or potassium salt. Water softeners may also remove varying amounts of other inorganic pollutants such as dissolved metals. However, they do not remove particles, pathogens, organic chemicals, or radon gas. They work best if the water is particulate free (filtered).

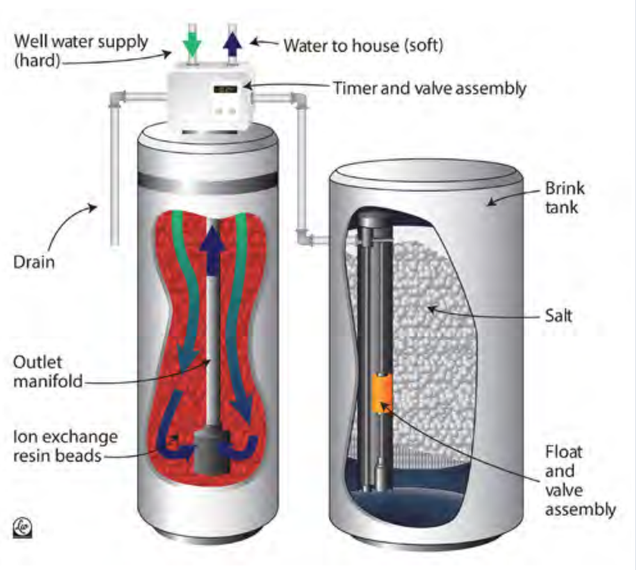


Figure 56. A water softener.

Do not use soft water, especially if it has high sodium levels, to water houseplants, garden vegetables, or yard plants that do not tolerate salinity well. Soft water may not be suitable for drinking because it tastes salty and contains higher levels of sodium. To counter this problem, newer water-softening units exchange calcium with potassium.

Replacing hardness with salinity will extend the life of household appliances and hot water heaters, but the increased salinity may damage the soils in a septic leach field.

Disinfection

To make water safe to drink, pathogens must be either filtered out of the water or killed (inactivated). Except for distillation, the filtration methods discussed above are not suitable for continuous removal of bacteria.

As a rule, water is disinfected by chemicals such as chlorine or ultraviolet (UV) radiation. Disinfection does not remove inorganic contaminants from water, but it may react with them and form by-products that may be of concern, such as chloroform.

A UV radiation unit consists of a clear glass tube surrounded by UV lights. The radiation inactivates the bacteria and pathogens as the water passes through the tube. If the water is cloudy, the unit will not work efficiently; for this reason, a UV treatment system should be installed after the particulates have been filtered from the water.

Continuous Chlorination of Domestic Wells

Chlorine kills pathogens when it has enough contact time, which is the amount of time that the water is mixed with chlorine. City water systems add extra chlorine to drinking water to ensure adequate contact time while the water is flowing through the pipes. This additional chemical is what makes treated water smell of chlorine.

Private domestic water can be chlorinated by chlorine pumps, solid feed units, and batch disinfectors. Chlorination treatment systems should be installed by a professional to ensure that they have been designed properly. The chlorine-injection device should operate only while the water is being pumped, and the pump should switch off if the chlorinator fails or if the chlorine supply is depleted.

Note: The chlorination process forms disinfection by-products, such as chloroform, by mixing chlorine with other constituents in the well water. Some of these chemicals are health hazards (Appendix B). For this reason, many municipal drinking water providers are switching from chlorination to other disinfection treatment systems.

Well owners chlorinating their water should have it tested for excessive levels of disinfection by-products in the treated water.

Boiling

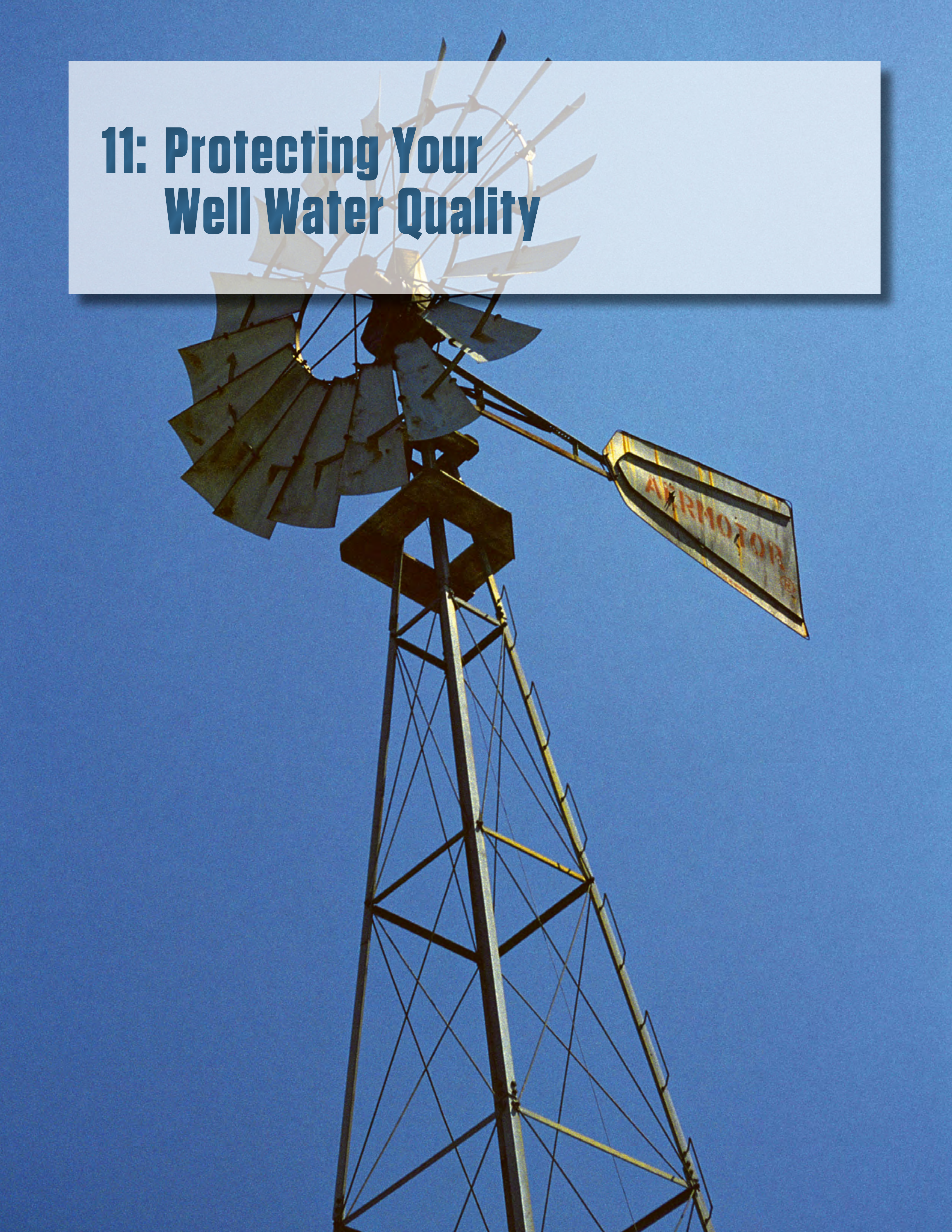
Boiling water vigorously for 2 minutes kills all organisms in water; chlorination only reduces them to safe levels. But because boiling also concentrates minerals and salts, it should be used only as an emergency measure. Also, the boiled water must be protected from re-contamination as it cools.

Emergency Disinfection

Only under emergency situations should household chemicals such as bleach or iodine be used to disinfect water without the appropriate equipment or technical supervision. The EPA explains how to use these chemicals safely at *https://www.epa.gov/ground-water-and-drinking-water/emergency-disinfection-drinking-water*.

Notes

11: Protecting Your Well Water Quality



Well water can be contaminated by other than natural sources (Fig. 57), most commonly:

- When the well is being installed or maintained,
- At the wellhead, where surface water can seep into the well,
- From septic system leach fields or septic failure, or
- By other land use activities near the well.

Well Installation and Maintenance

Although licensed well drillers and pump installers are trained to prevent contaminants from entering a well, bacteria sometimes still enter during well construction or routine maintenance. Follow these steps to prevent or reduce bacteria in the water:

- Check your plumbing, water storage, and treatment systems every month. If you see any algae, slime, or discolored filtering media, it could indicate that the system is contaminated with bioslime. It will need to be scrubbed and then rinsed with chlorine bleach, and the filtering media will need to be replaced.
- If you suspect any well casing or pump failure, have a licensed well driller or pump installer inspect the system. Older wells, especially those made of black iron or steel, can corrode and break.
- Test the water for bacteria after any well maintenance. Bacteria can be introduced when the pump or drop pipe is laid on the ground during maintenance. The bacteria can then grow into mats of bioslime inside the well.
- If bacteria are found, have the well shock-chlorinated and its interior physically scrubbed. Shock chlorination, well cleaning, and well and pump maintenance are best conducted by a professional well driller or pump installer.
- If you notice an oily sheen or odor, have the water tested for total petroleum hydrocarbons (TPH). Pump maintenance may introduce oils and grease into the well that can foul the well water or provide a source of nutrition for naturally occurring soil bacteria.
- If there is any evidence of flooding, have the well water tested for bacteria.
- Make sure that all faucets with hose connections are equipped with anti-backflow devices such as check valves.

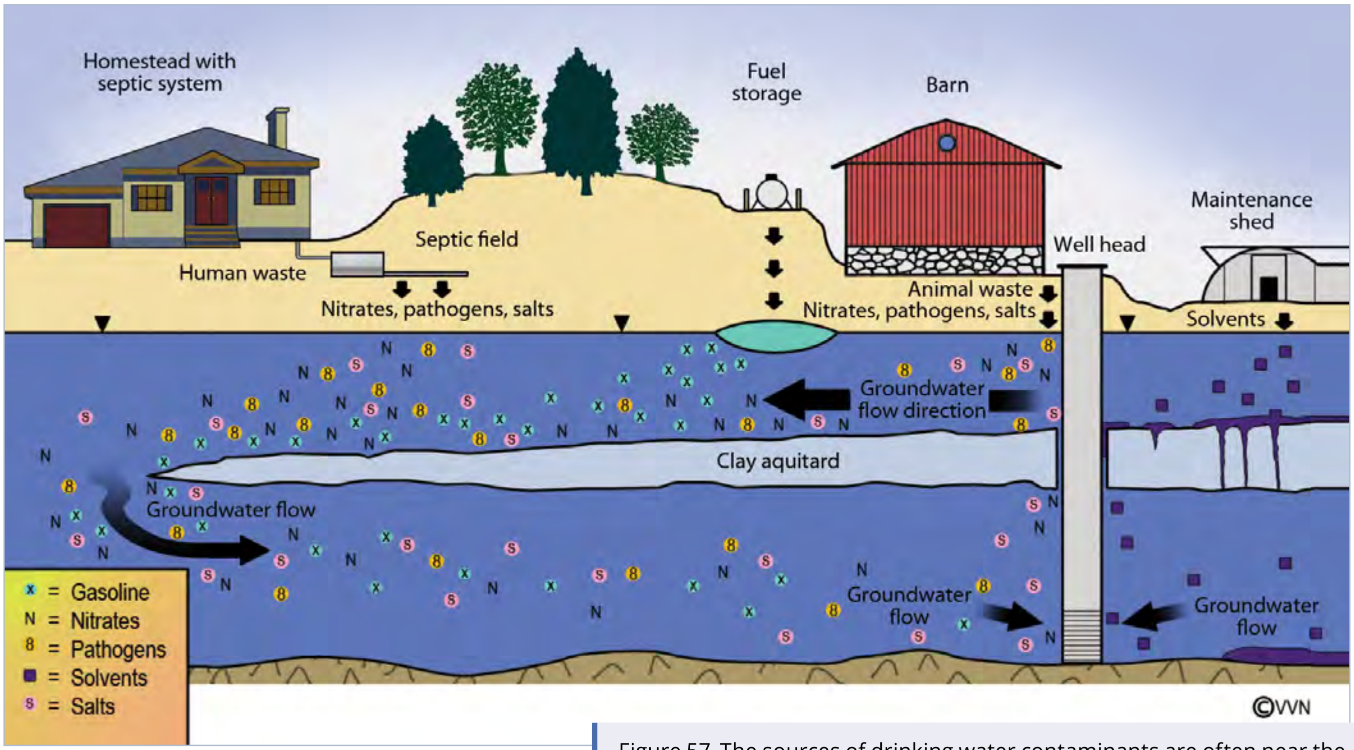


Figure 57. The sources of drinking water contaminants are often near the wellhead and may include septic leach fields, and/or land use activities.

Wellhead Protection

Because each well provides a direct route to the aquifer, you will need to take special precautions to protect the wellhead (Fig. 58). Once groundwater is contaminated, it is very difficult to restore, and most remediation options are costly.

If your well was installed by a licensed well driller after 1983, it complies with Texas regulations on wellhead construction. As discussed in Chapter 5, the well protective casing should be at least 1 foot above the ground and be surrounded by a 4-inch-thick concrete pad for at least 2 feet in all horizontal directions.

This configuration protects the well from flooding or ponded water; it reduces the potential for contaminants to seep down into the aquifer around the well casing (Fig. 59).

Chemicals pose serious threats to groundwater quality, and some can cause serious illness or death if consumed. Chemicals that do not readily mix with water are called *non-aqueous phase liquids,* or *NAPLs.*

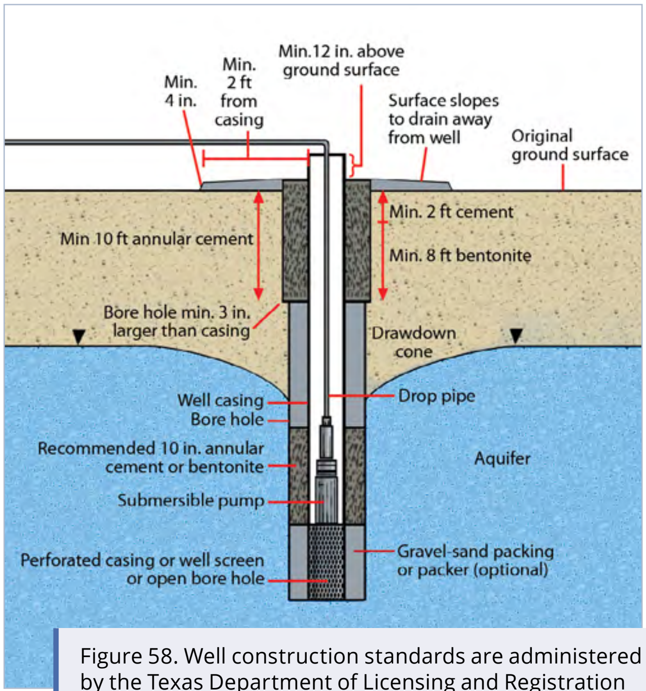


Figure 58. Well construction standards are administered by the Texas Department of Licensing and Registration (TDLR) to protect the aquifer and well from surface water ponding around the well head. Well construction and plugging specifications accepted by the TDLR are shown at *https://www.tdlr.texas.gov/wwd/wwdspecs.htm*.

Figure 59. The slab around this well is not sufficient to prevent surface contaminants from entering the aquifer. (Source: *Plugging Abandoned Water Wells*, Bruce Lesikar and Justin Mechell, 2010.)

NAPLs may be light or dense:

- Light NAPLs (LNAPLs) will float on the water table, like oil floats over vinegar in some salad dressings. Examples of LNAPLs are petroleum-based fuels such as gasoline and diesel. These fuels will pool on the water table and release chemicals such as benzene into the groundwater.
- Dense NAPLs (DNAPLs) are heavier than water. Typical DNAPLs are degreasers and solvents. They are extremely difficult to remediate and can contaminate the water permanently. Several cancers and childhood leukemia have been linked to parts per billion levels of chemical degreasers and solvents in groundwater.

Follow these steps to protect the wellhead from chemical contamination:

- Do not store or use chemicals near the wellhead.
- Do not mix pesticides, rinse tanks, or store gasoline within 150 feet of a well.
- If backflow-prevention devices are not installed on hoses, reduce the potential for backflow when mixing chemicals. First fill a "nurse" tank (mobile storage tank) with well water; then use that water to fill the chemical sprayer away from the wellhead.
- If the wellhead is in a storage shed or well house, do not store contaminants such as fuels or pesticides in it.
- Do not winterize the well by wrapping pipes and pressure tanks with empty fertilizer or pesticide bags or other materials containing potential contaminants.

Following these additional guidelines will help prevent other types of contamination at the wellhead (Fig. 60):

- Inspect the wellhead every month, and address any breakage, soil disturbance by burrowing animals, or flooding of the wellhead. The well owner can repair and maintain the wellhead pad; a licensed contractor should repair casing breakage.
- Locate pet holding areas at least 150 feet away and downslope of the wellhead. Pet waste from dog runs and yards can contaminate groundwater.
- Build livestock holding areas at least 150 feet away and downslope of the wellhead, and direct stormwater runoff away from the wellhead. Runoff from livestock holding pens and pastures can contaminate groundwater with bacteria, nitrates, and veterinary drugs.
    - Locate manure stacks and liquid waste lagoons more than 250 feet from the wellhead.
    - Cover and protect compost stacks and wet manure to prevent waste from running off and entering the soil.

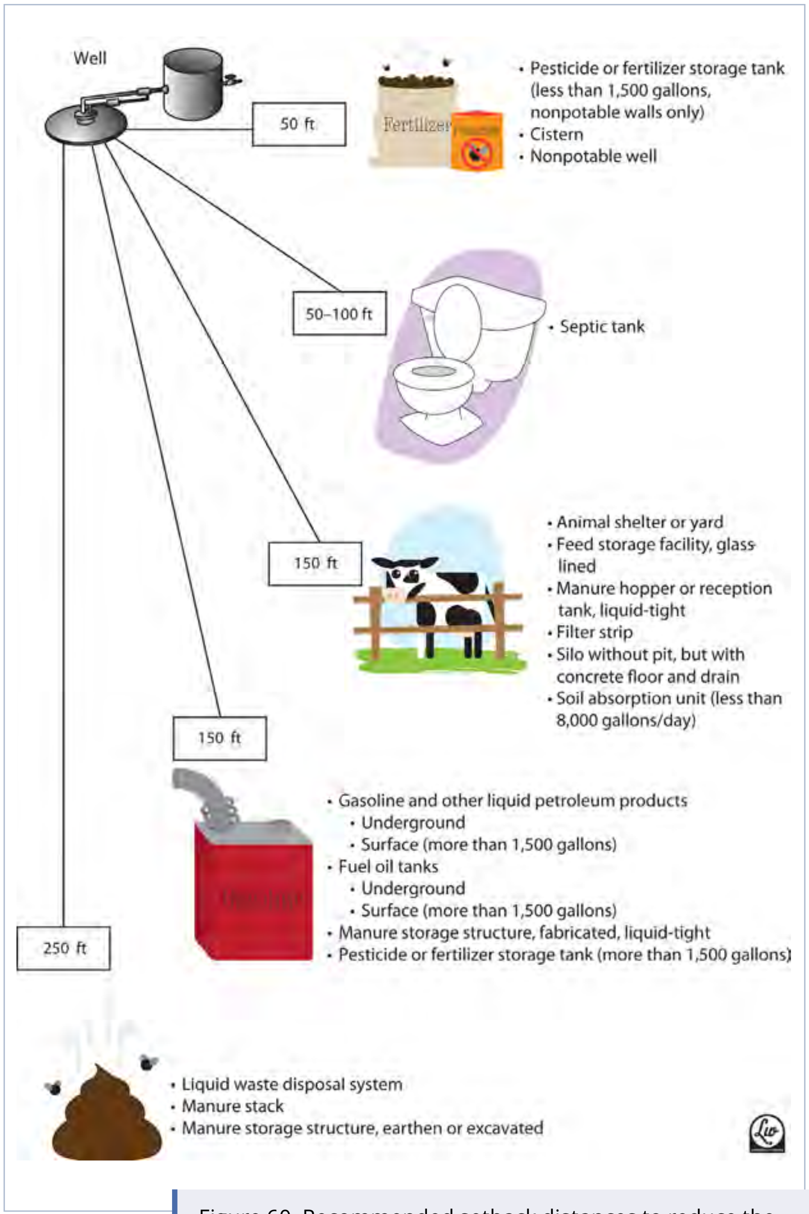


Figure 60. Recommended setback distances to reduce the risk of well water contamination by land use activities.

Household Wastewater Management and Onsite Septic Systems

Septic systems must be maintained regularly to avoid polluting the environment and causing health problems for people. To operate and maintain an onsite septic system effectively, first understand how it works and what affects it.

The most common onsite wastewater treatment system is a conventional septic system (Fig. 61). This type of system consists of a septic tank and a soil absorption or drain field.

The system treats wastewater in the tank and in the drain field:

1. Wastewater flows through pipes from the house to the septic tank, which is a watertight container where solids are separated from liquid wastes.
2. In the tank, microorganisms (also called *microbes*) begin consuming the solids, nutrients, and organic matter in the wastewater.
3. The wastewater then moves through perforated pipes to a bed of gravel or similar material.
4. From the gravel bed, the wastewater moves into the

soil, where microbes consume more of the contaminants.

5. The water then moves through the soil and evaporates, is used by plants, or moves to groundwater.

Different types of onsite wastewater treatment systems require different maintenance procedures. However, all systems need maintenance. They will malfunction if not maintained.

Follow these guidelines to keep your system operating properly and to avoid contaminating the groundwater:

- Locate the septic tank at least 50 feet from the wellhead; the drain field should be at least 100 feet from the wellhead.
- Do not use in-sink garbage disposals excessively.
- Divert runoff coming from driveways and rooftops away from the soil treatment area.
- Do not dump grease or medications down the drain or into a toilet. Do not use the toilet as a trash can.
- If you are undergoing chemotherapy, ask your doctor about appropriate waste disposal methods to avoid discharging toxic drugs into the environment.
- Do not use chemicals to clean the septic system. They can interfere with the biological action in the tank, add toxic chemicals to groundwater, and clog the drain field by flushing sludge and scum into the field.
- Have the septic tank cleaned every 2 to 3 years.
- Do not add chemical additives such as enzymes or conditioners to the septic tank.
- Do not cover the drain field with an impervious surface such as a driveway or parking area.
- Do not drive heavy equipment over the components of a wastewater treatment system.
- Because septic systems do not remove nitrogen compounds efficiently, have the well water tested for nitrate every year. One of the most common contaminants found in domestic drinking water wells is nitrate.
- Conserve water in the home to reduce the amount of water that the wastewater treatment system must process. Excessive amounts of water can overload the system and cause it to fail.

Other problems to watch for include:

- Roots from trees and other vegetation may clog and damage the system.
- Some drinking water treatment systems, such as reverse osmosis systems, can discharge up to 60 percent of the amount of water pumped.

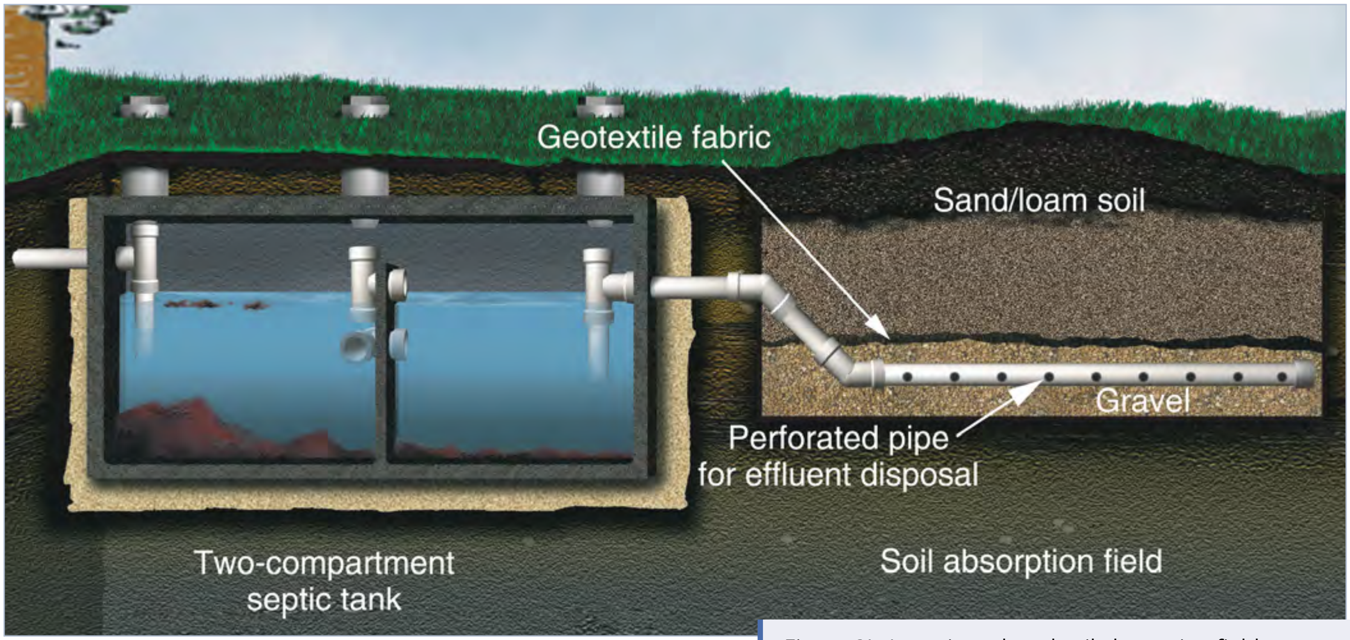


Figure 61. A septic tank and soil absorption field system.

- Spent brine discharge from reverse osmosis and water softeners will increase the concentrations of salt in the soil, which could change the soil structure in the leach field and cause the system to fail.

For more information, see the *Onsite Wastewater Treatment Systems: Operation and Maintenance* publication by Texas A&M AgriLife Extension at *https://agrilifelearn.tamu.edu/s/product/owts-operation-and-maintenance/01t4x000004OfYRAA0*.

Plugging Abandoned Wells

Under Texas law, the landowners are responsible for plugging abandoned wells on their property and are liable for any groundwater contamination or injury that results from the wells.

Like other wells, an abandoned well (Fig. 62) is a direct channel from the ground surface to the aquifer below. Contaminants that enter the well move directly into the aquifer. If a concentrated chemical enters a well, it may move into the aquifer and threaten human health and the environment. It also puts other wells in the same aquifer at risk for contamination, particularly those on the same property or those close to the abandoned well.

Before you begin the process of plugging an abandoned well, notify the local groundwater conservation district. Some districts place restrictions on the type of well and depth of water in the well that a landowner may decommission. In some cases, you will need to hire a licensed water well driller or pump installer to seal and plug the abandoned well.

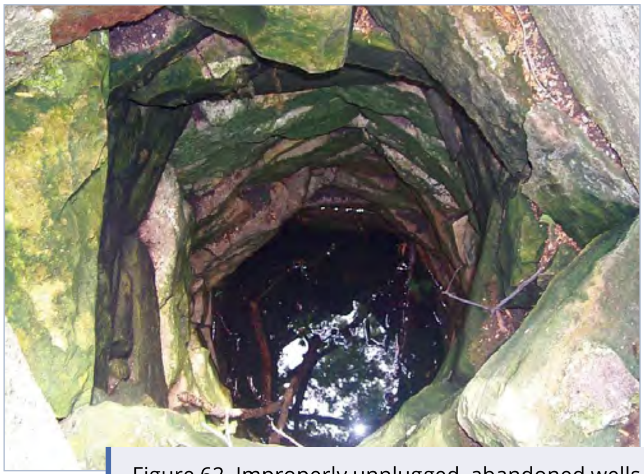


Figure 62. Improperly unplugged, abandoned wells can be a source of groundwater contamination.

You are required to notify the Water Well Drillers Program of the Texas Department of Licensing and Regulation of your intent to plug the well and the method to be used. Also, send a copy of the state well-plugging form to the local groundwater conservation district.

For instructions on how to plug a well properly, see

- *Plugging Abandoned Water Wells,* by the Texas A&M AgriLife Extension Service at *https://agrilifelearn.tamu.edu/s/global-search/plugging* or at *https://abandonedwell.tamu.edu/*.
- *Landowner's Guide to Plugging Abandoned Water Wells,* by the Texas Groundwater Protection Committee, at *https://www.tceq.texas.gov/downloads/groundwater/publications/landowners-guide-to-plugging-abandoned-water-wells-rg-347.pdf*.
- The Texas Groundwater Protection Committee website at *https://tgpc.texas.gov*.

Shock Chlorination of Water Wells

When a water system is contaminated with bacteria, the well can be disinfected by shock chlorination. This process introduces very high concentrations of chlorine directly into the well and plumbing system. Chlorine is highly toxic to bacteria.

To reduce your risk of exposure to hazardous chemicals and protect the system components, have a licensed water well driller or pump installer conduct the procedure.

If you want to shock-chlorinate the well yourself, follow the instructions in the Texas A&M AgriLife Extension Service publication, Shock Chlorination of Wells, at *https://twon.tamu.edu/wp-content/uploads/sites/3/2021/06/esc059.pdf*. Also review the owner's manual or manufacturer's literature to avoid damaging the water treatment system components. Take precautions to reduce your exposure to fumes.

Schedule shock chlorination for when the water system will not be in use for at least 12 to 24 hours.

Calculate the amount of chlorine needed according to the amount of water standing in the well. You'll need access to the well to measure its depth and volume of water. If clear access is not possible, hire a licensed professional.

In addition to the well, most water treatment equipment—including water heaters, softeners, and pressure tanks—should be disinfected. During the process, temporarily disconnect or bypass drinking water filters such as activated carbon filters.

During and immediately after the disinfection process, the water from the system will be unsuitable for consumption. You will need to flush the water system until all traces of chlorine are gone and the well water has been tested. Do not allow the water to be used for drinking until test results confirm that the water is safe.

In some cases, multiple shock chlorination procedures are not enough to resolve the problem. In those situations, a licensed well driller or pump installer will need to remove the pump and plumbing from the well and swab the interior with brushes and chemicals made for this purpose.

When you introduce chlorine, some of the chemical may enter the aquifer through the well screen. **When the geologic material of the aquifer is exposed to chlorine, other constituents such as arsenic may dissolve and enter the water supply.**

Hydraulic fracturing

Another concern for some well owners is hydraulic fracturing (fracking), a procedure in which a large amount of water is sent under pressure into a borehole to fracture the rock underground. The process is used to increase yields from aquifers, oil and gas reservoirs, and salt solution mining operations. In the water well industry, hydraulic fracturing can double a well's yield.

Hydraulic fracturing is not a new technology; companies have used hydraulic fracturing procedures for decades. However, new technology has made it more prevalent.

Points of concern for water well owners include the gases that can be released after hydraulic fracturing, the large amount of water it requires, and the wastewater generated in the process.

Gases: Groundwater is not expected to contain dissolved methane or hydrocarbons. However, they may be present naturally if the aquifer is located near an oil- or gas-producing zone.

Hydraulic fracturing may release these constituents into the environment. Coal beds may release methane. If you suspect that you well water contains these constituents, have it tested as discussed in Chapter 9.

Water use: Several million gallons of water are needed for each hydraulic fracturing process, and a well can be fracked multiple times over the length of the borehole. Some well owners have expressed concern that pumping water from a water-supply aquifer or a surface-water source will affect private wells as well as reduce the amount available for other uses.

Wastewater: The wastewater from hydraulic fracturing oil and gas wells often contains high concentrations of total dissolved solids. This water will also contain the original fracking solution and some of the hydrocarbon constituents released from the oil or gas reservoir.

This wastewater must be disposed of properly. Contact these agencies if you suspect water contamination caused by wastewater discharge:

- The Texas Railroad Commission (*www.rrc.state.tx.us*) regulates wastewater management from oil and gas development.
- The Texas Commission on Environmental Quality (*https://www.tceq.texas.gov/agency/water_main.html*) regulates wastewater treatment facilities.

References

Lesikar, B. 2008. *Onsite Wastewater Treatment Systems Operation and Maintenance.* Texas A&M AgriLife Extension Service. College Station, TX.

Lesikar, B. and J. Mechell. 2010. *Plugging Abandoned Water Wells.* Texas A&M AgriLife Extension Service. College Station, TX.

McFarland, M. L., M. C. Dozier, and R. C. Runyan. 2003. *Shock Chlorination of Wells.* Texas A&M AgriLife Extension Service, College Station, TX.

Texas Groundwater Protection Committee. 2010. *Landowner's Guide to Plugging Abandoned Water Wells.* RG-347, *https://www.tceq.texas.gov/downloads/groundwater/publications/landowners-guide-to-plugging-abandoned-water-wells-rg-347.pdf.*

Notes

Appendix A
Agencies and Organizations: Where to Find Help

Table 5.Information available on water wells and groundwater	
Aquifers in Texas, maps	Texas Water Development Board (TWDB), *www.twdb.texas.gov*
Emergency water disinfection	U.S. Environmental Protection Agency (EPA), *https://www.epa.gov/ground-water-and-drinking-water/emergency-disinfection-drinking-water*
Enforcement of well construction regulations	Texas Department of Licensing and Regulation, *www.tdlr.texas.gov*
Environmental information, local	MyEnvironment, EPA, *https://enviro.epa.gov/*
Groundwater information for students	Ground Water Adventurers, National Ground Water Association, *www.groundwateradventurers.org*
Groundwater information, world: science, development, economics, management, and protection	National Ground Water Association, a nonprofit group of U.S. and international groundwater professionals, including contractors, engineers, equipment manufacturers, scientists, and suppliers. Provides information to members, governmental agencies, and the public, *www.ngwa.org/*
Groundwater management areas	TWDB, *https://www.twdb.texas.gov/groundwater/management_areas/index.asp*
Groundwater conservation districts	Texas Alliance for Groundwater Districts, *www.texasgroundwater.org/*
Hydrologic sciences basic course	Cooperative Program for Operational Meteorology, Education and Training, *https://www.comet.ucar.edu/.* Key terminology, hydrologic processes, case studies, and some modules in Spanish.
Laboratories that test drinking water, listing	County health department National Environmental Laboratory Accreditation Conference Institute, *http://www.nelac-institute.org/*
Laws pertaining to water in Texas	Texas Water Code §35.001, *https://statutes.capitol.texas.gov/Docs/WA/htm/WA.35.htm*
Licensing and registration of well drillers and pump installers	Texas Department of Licensing and Regulation, *www.tdlr.texas.gov*
Oil and gas development, wastewater management	Texas Railroad Commission, *www.rrc.state.tx.us*
Primary drinking water contaminants	EPA, *https://www.epa.gov/sdwa/drinking-water-regulations-and-contaminants*
Pump installers and well drillers, listing	Texas Department of Licensing and Regulation, *https://www.tdlr.texas.gov/LicenseSearch/*
Quality of drinking water, public	Safe Drinking Water Act, *https://www.epa.gov/sdwa*
Quality of groundwater, effects of wastewater treatment facilities and other sites	Texas Commission on Environmental Quality (TCEQ), *https://www.tceq.texas.gov/agency/water_main.html*

Table 5.Information available on water wells and groundwater	
Quality of groundwater, local	Local Ground Water Conservation District, *https://www.twdb.texas.gov/groundwater/conservation_districts/index.asp*
Quality of well water, professionals	Local licensed plumbers, pump installers, and well drillers Texas Department of Licensing and Regulation, *www.tdlr.texas.gov* Texas Groundwater Protection Program, *https://www.tceq.texas.gov/groundwater/groundwater-planning-assessment/prot_prog.html*
Superfund toxic waste locations	EPA, *www.epa.gov/superfund/*
Water level recorder wells	*waterdatafortexas.org/groundwater*
Water treatment systems, standards and certification	American National Standards Institute, *www.ansi.org* National Sanitation Foundation, *www.nsf.org/certified/dwtu*
Water well information, general	Texas Groundwater Protection Committee provides information important to well owners and coordinates among agencies involved in groundwater activities, *www.tgpc.state.tx.us/* National Ground Water Association, *www.wellowner.org*
Water well information, Texas	Texas Water Development Board Groundwater Database, information on 130,000 wells, including well design yield and pump capacity, *http://wiid.twdb.texas.gov/ims/wwm_drl/viewer.htm* Water Well Report, TCEQ, *https://www.tceq.texas.gov/gis/waterwellview.html* TCEQ Records Services Department, 512.239.0900
Well drillers and pump installers, listing	Texas Department of Licensing and Regulation, *www.tdlr.texas.gov*

Appendix B
National Primary Drinking Water Standards

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public health goal
OC	Acrylamide	TT[8]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	0
OC	Alachlor	0.002	Eye, liver, kidney, or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	0
R	Alpha particles	15 picocuries per liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	0
IOC	Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
IOC	Arsenic	0.010 as of 1/23/06	Skin damage, problems with circulatory system, and may have increased risk of cancer	Erosion of natural deposits; runoff from orchards, runoff from glass and electronics production wastes	0
IOC	Asbestos (fibers >10 micrometers)	7 million fibers per liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
OC	Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
IOC	Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
OC	Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	0
OC	Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	0
IOC	Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries	0.004
R	Beta particles and photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain materials that are radioactive and may emit forms of radiation known as photons and beta radiation	0
DBP	Bromate	0.010	Increased risk of cancer	Byproducts of drinking water disinfection	0

LEGEND: **D** Disinfectant, **DBP** Disinfection byproduct, **IOC** Inorganic chemical, **M** Microorganism,
OC Organic chemical, **R** Radionuclide

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public health goal
IOC	Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005
OC	Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04
OC	Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	0
D	Chloramines (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation, stomach discomfort, anemia	Water additive used to control microbes	MRDLG=4[1]
OC	Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	0
D	Chlorine (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=4[1]
D	Chlorine dioxide (as ClO_2)	MRDL=0.8[1]	Anemia; infants and young children: nervous system effects	Water additive used to control microbes	MRDLG=0.8[1]
DBP	Chlorite	1.0	Anemia; infants and young children: nervous system effects	Byproduct of drinking water disinfection	0.8
OC	Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1
IOC	Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1
IOC	Copper	TT[7]; action level=1.3	Short-term exposure: Gastrointestinal distress. Long-term exposure: Liver or kidney damage. People with Wilson's disease should consult a doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3
M	*Cryptosporidium*	TT[3]	Gastrointestinal illness (diarrhea, vomiting, cramps)	Human and animal fecal waste	0
IOC	Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC	2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC	Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC	1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Reproductive difficulties, increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	0
OC	o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC	p-Dichlorobenzene	0.075	Anemia; liver, kidney, or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC	1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	0

LEGEND: **D** Disinfectant, **DBP** Disinfection byproduct, **IOC** Inorganic chemical, **M** Microorganism, **OC** Organic chemical, **R** Radionuclide

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public health goal
OC	1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC	cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC	trans-1,2-Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC	Dichloromethane	0.005	Liver problems, increased risk of cancer	Discharge from drug and chemical factories	0
OC	1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	0
OC	Di(2-ethylhexyl) adipate	0.4	Weight loss, liver problems, possible reproductive difficulties	Discharge from chemical factories	0.4
OC	Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties, liver problems; increased risk of cancer	Discharge from rubber and chemical factories	0
OC	Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables	0.007
OC	Dioxin (2,3,7,8-TCDD)	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories	0
OC	Diquat	0.02	Cataracts	Runoff from herbicide use	0.02
OC	Endothall	0.1	Stomach and intestinal problems	Runoff from herbicide use	0.1
OC	Endrin	0.002	Liver problems	Residue of banned insecticide	0.002
OC	Epichlorohydrin	TT[8]	Increased cancer risk, and over a long period, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals	0
OC	Ethylbenzene	0.7	Liver or kidney problems	Discharge from petroleum refineries	0.7
OC	Ethylene dibromide	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries	0
IOC	Fluoride	4.0	Bone disease (pain and tenderness of the bones); children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories	4.0
M	*Giardia lamblia*	TT[3]	Gastrointestinal illness (such as diarrhea, vomiting, cramps)	Human and animal feces	0
OC	Glyphosate	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use	0.7
DBP	Haloacetic acids (HAA5)	0.060	Increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Heptachlor	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide	0
OC	Heptachlor epoxide	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor	0

LEGEND: **D** Disinfectant, **DBP** Disinfection byproduct, **IOC** Inorganic chemical, **M** Microorganism, **OC** Organic chemical, **R** Radionuclide

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public health goal
M	Heterotrophic plate count (HPC)	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment	n/a
OC	Hexachlorobenzene	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories	0
OC	Hexachlorocyclopent-adien	0.05	Kidney or stomach problems	Discharge from chemical factories	0.05
IOC	Lead	TT[7]; action level = 0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits	0
M	*Legionella*	TT[3]	Legionnaire's disease, a type of pneumonia	Found naturally in water; multiplies in heating systems	0
OC	Lindane	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens	0.0002
IOC	Mercury (inorganic)	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands	0.002
OC	Methoxychlor	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock	0.04
IOC	Nitrate (measured as nitrogen)	10	Infants under 6 months old who drink water containing nitrate in excess of the MCL could become seriously ill and if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	10
IOC	Nitrite (measured as nitrogen)	1	Infants under 6 months old who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	1
OC	Oxamyl (Vydate)	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes	0.2
OC	Pentachlorophenol	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories	0
OC	Picloram	0.5	Liver problems	Herbicide runoff	0.5

LEGEND: **D** Disinfectant, **DBP** Disinfection byproduct, **IOC** Inorganic chemical, **M** Microorganism, **OC** Organic chemical, **R** Radionuclide

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public health goal
OC	Polychlorinated biphenyls (PCBs)	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals	0
R	Radium 226 and radium 228 (combined)	5 pCi/L	Increased risk of cancer	Erosion of natural deposits	0
IOC	Selenium	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines	0.05
OC	Simazine	0.004	Problems with blood	Herbicide runoff	0.004
OC	Styrene	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	0.1
OC	Tetrachloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	0
IOC	Thallium	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories	0.0005
OC	Toluene	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories	1
M	Total coliforms (including coliform and *E. coli*)	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment as well as feces; fecal coliforms and *E. coli* come only from human and animal feces	0
DBP	Total trihalomethanes (TTHMs)	0.10 0.080 after 12/31/03	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Toxaphene	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle	0
OC	2,4,5-TP (Silvex)	0.05	Liver problems	Residue of banned herbicide	0.05
OC	1,2,4-Trichlorobenzene	0.07	Changes in adrenal glands	Discharge from textile finishing factories	0.07
OC	1,1,1-Trichloroethane	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	0.20
OC	1,1,2-Trichloroethane	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories	0.003
OC	Trichloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories	0

LEGEND: **D** Disinfectant, **DBP** Disinfection byproduct, **IOC** Inorganic chemical, **M** Microorganism, **OC** Organic chemical, **R** Radionuclide

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public health goal
M	Turbidity	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (such as whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff	n/a
R	Uranium	30 ug/L as of 12/08/03	Increased risk of cancer, kidney toxicity	Erosion of natural deposits	0
OC	Vinyl chloride	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	0
M	Viruses (enteric)	TT[3]	Gastrointestinal illness (diarrhea, vomiting, cramps)	Human and animal feces	0
OC	Xylenes (total)	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories	10

Notes

1. Definitions
   - Maximum Contaminant Level Goal (MCLG)—The level of contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
   - Maximum Contaminant Level (MCL)—The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
   - Maximum Residual Disinfectant Level Goal (MRDLG)—The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
   - Maximum Residual Disinfectant Level (MRDL)—The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
   - Treatment Technique (TT)—A required process intended to reduce the level of a contaminant in drinking water.
2. Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (ppm).
3. EPA's surface water treatment rules require systems using surface water or groundwater under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels.
   - *Cryptosporidium* (as of 1/1/02 for systems serving >10,000 and 1/14/05 for systems serving <10,000): 99% removal.
   - *Giardia lambia:* 99.9% removal/inactivation
   - Viruses: 99.99% removal/inactivation
   - *Legionella:* No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.
   - Turbidity: At no time can turbidity (cloudiness of water) go above 5 nephelometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, for systems serving >10,000, and January 14, 2005, for systems serving <10,000, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
   - HPC: No more than 500 bacterial colonies per milliliter.
   - Long Term 1 Enhanced Surface Water Treatment (Effective Date: January 14, 2005): Surface water systems or (GWUDI) systems serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (such as turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).
   - Filter backwash recycling: The Filter Backwash Recycling Rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.
4. No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* of two consecutive TC-positive samples, and one is also positive for *E. coli* fecal coliforms, system has and acute MCL violation.
5. Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.
6. Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:
   - Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.3 mg/L)
   - Trihalomethanes bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L)
7. Lead and copper are regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.
8. Each water system must certify, in writing, to the state (using third-party or manufacturers certification) that when it uses acrylamide and/or epichlorohydrin to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: acrylamide=0.05% dosed at 1 mg/L (or equivalent); epichlorohydrin=0.01% dosed at 20 mg/L (or equivalent).

Appendix C

Water Problems: Symptoms, Tests, and Possible Sources

	Symptom	Cause	Treatment devices
Visual (water appearance)	Cloudiness of water with a yellow, brown, or black cast that clears after standing 24 hours	Turbidity	Flocculation and sedimentation or particle and microfiltration (POE)[2]
	Transparent yellow-brown tint to water that doesn't clear after standing 24 hours	High levels of NOM[2], usually in surface water	Activated carbon filtration or chlorination followed by activated carbon filtration Water utilities use flocculation to remove NOM.[1]
	Brown-orange stains or reddish slime or tint to water	Presence of dissolved iron and iron bacteria	Low amounts: reduce with particle filter or during reverse osmosis or distillation treatments (POE[2] or POU[3]) High amounts: remove by potassium permanganate-regenerated oxidizing filter and particle filter (POE)[2] Very high amounts: remove by chlorination followed by particle filter (POE)[2] Consider well and distribution/storage shock chlorination to kill iron bacteria
	Brownish color or rusty sediment	Suspended iron and manganese particles	Particle filter (POE)[2]
Visual (staining and deposits)	Blackened or tarnished metal utensils and pipes	High chloride and sulfate levels	Reverse osmosis unit (POE)[2] or distillation unit (POU)[3]
	Blackened or tarnished metal utensils and pipes	High water acidity and high hydrogen sulfide	Acid-neutralizing filters (calcite or calcite/magnesium oxide) (POE)[2] or addition of alkaline chemicals such as lime
	Stains in showers, toilet bowls, and faucet ends	Hardness	Water softener (POE[2] or POU[2])

	Symptom	Cause	Treatment devices
Visual (staining and deposits) continued	Excessive staining in showers and aluminum cookware	Salinity	Reverse osmosis unit or distillation unit (POU)[2]
	Green water stains	Acidity	Acid neutralizing filters (POE)[2] or addition of alkaline chemicals such as lime
	Soap deposits or excessive scaly deposits in plumbing and appliances	Hardness	Water softener or reverse osmosis or distillation (POE[2] or POU[2])
	Excessive salt deposits	Alkalinity (high pH and sodium)	Reverse osmosis or distillation systems (POE[2]) consider acid neutralization of excessive alkalinity
Other visual	Houseplants stunted or with burned leaf tips	Salinity	Reverse osmosis unit or distillation unit (POU)[2]
Taste	Taste of chlorine, gasoline, or oil	VOCs[4], including residual chlorine, disinfection byproducts, pesticides, or fuel (gasoline, diesel, oil products)	Activated charcoal filter or aeration (POE)[2]
	Metallic taste	Acidity	Acid neutralizing filters (POE)[2] or addition of alkaline chemicals such as lime
	Salty or bitter taste	High total dissolved solids, sodium, sulfates, or nitrates (salinity)	Reverse osmosis or distillation (POU)[3]
Odor	Chlorine-like odor	VOCs, including residual chlorine, disinfection byproducts, pesticides, gasoline products	Activated charcoal filter or aeration (POU)
	Gasoline-like odor	Gasoline, diesel, oil products	Activated charcoal filter or aeration (POU)
	Earthy, musty, or chemical odor	Algae products (geos-min and MIB)	Activated charcoal filter (POU)
	Rotten egg odor	Excessive acidity, lack of oxygen in water source, or contamination by hydrogen sulfide gas (occurs naturally in aquifers and sediments)	Oxidation of water during aeration (POE) or chlorination and a particle filter (POE) or oxidizing filter (POE) followed by an activated carbon filter Acidity control may also be needed

	Symptom	Cause	Treatment devices
Illness	Gastrointestinal problems such as diarrhea and vomiting	Pathogens	Remove source of contamination. Reduce pathogens through chlorination, UV radiation, or ozonation (POE). Chloramine chemicals may be used after chlorination is completed in order to maintain acceptable chlorine residual levels.
Appliance/hardware problems	Early appliance failure	Hardness	Water softener (POE or POU)
	Poor evaporative cooler performance	Build-up of scale on pads (high hardness, high salinity)	Use bleed-off mechanism to prevent build-up of salts and minerals (more information on Water Conservation website)
	Blackened/tarnished metal utensils and pipes	High chloride levels	Reverse osmosis unit or distillation unit (POU)
	Blackened/tarnished metal utensils and pipes	High water acidity and high hydrogen sulfide	Acid-neutralizing filters (POE) or addition of alkaline chemicals such as lime

[1] NOM - Natural organic water
[2] POE - Point of entry
[3] POU - Point of use
[4] VOC - Volatile organic compound

Glossary

Can't find it here? More water-related terms are posted at *http://www.aces.edu/waterquality/glossary/glossary.htm.*

aeolian: Pertaining to a sedimentary process affected by the activity of wind. Winds erode, transport, and deposit materials and form unconsolidated land forms such as sand dunes. The term is derived from the name of the mythological Greek god Aeolus, keeper of the winds.

alluvial: Pertaining to a sedimentary process made by running water. The alluvial sedimentary deposits may be in river beds, flood plains, and alluvial fans. It does not include sediments in lakes or seas.

alluvial fan: An outspread, gently sloping landform of alluvium deposited by a combination of gravity and stream flow. It is found in arid and semiarid regions. Viewed from above, the landform is in the shape of a fan.

alpha particle: A particle emitted from an atomic nucleus during radioactive decay; it can be stopped by a sheet of paper. See *beta particle* and *gamma ray.*

annular space: In well drilling, the space between the well casing and the borehole wall.

anthropogenic: Relating to or resulting from the influence of human beings.

aquifer: An underground body of geologic material that is permeable enough to conduct groundwater and to yield water to a well.

aquitard: An underground body of geologic material such as clay that slows groundwater flow and is not permeable enough to yield water to a well.

artesian: Pertaining to groundwater that is under enough pressure to rise above the aquifer containing it.

basement rock: The crust of the earth beneath sedimentary deposits. Basement rock is usually igneous and metamorphic rock such as granite.

basalt: A dark igneous rock commonly extruded from volcanoes.

basin and range province: An area having a series of fault-block mountains, which are large blocks of rock created by rifts; the mountains are separated by basins filled with sediment.

beta particle: A high-energy, high-speed particle emitted from an atomic nucleus during radioactive decay. A beta particle has more energy than an alpha particle. It can penetrate paper but will be stopped by an aluminum plate. See *alpha particle* and *gamma ray.*

bioslime: A colony of microorganisms that attach to each other and to a surface, forming slime.

caliche: A hardened deposit of calcium carbonate that cements together other materials, such as clay, gravel, sand, silt, and soil. Caliche is typically found on or near the ground surface in arid and semiarid regions. It can be a few inches to a few feet thick.

colloidal: Consisting of substances or particles that are microscopically and evenly dispersed throughout a liquid.

colluvium: A loose body of sediment that has been deposited by gravity. Colluvium is deposited by activities such as avalanches, mudslides, and landslides.

confined (unconfined): An aquifer that has a confining layer (aquitard) between it and the land surface. An artesian aquifer is confined, but not all confined aquifers are artesian (under pressure).

consolidated: Said of geologic material that has undergone any process whereby loose, soft, or liquid earth materials have become firm and hard. An example of consolidated material is rock.

contact time: In water disinfection, the length of time required for chlorine or another disinfectant to deactivate pathogens.

corrosion: The disintegration of an engineered material by chemical reactions with its surroundings. An example is the rusting of an iron pipe.

delta: A nearly flat, alluvial tract of land at the mouth of a river; it is formed by the deposition of sediment and alluvium by the river. Most deltas are partly submerged.

depositional setting: The laying-down of geologic material by any natural agent, such as when river systems transport sediment or it settles from suspension in water.

distillation: A method of separating mixtures based on differences in volatilities of components in a boiling liquid mixture. Water is distilled to remove impurities, such as salt from seawater. Distilled water consists of water molecules only.

divide (watershed): The topographic boundary between two watersheds.

down gradient: Downhill or down slope—the direction that groundwater flows under a gradient.

drawdown cone (cone of depression): The lowering of the water level in a well as a result of pumping. The drawdown is the vertical distance between the original water table and the water level in a well; the cone of depression is the horizontal distance between the well and the edge of the drawdown.

enteric: Of or within the intestine.

EPA (Environmental Protection Agency): A U.S. governmental agency that works to protect human health and the environment.

evaporite: Sediment deposited after a liquid evaporates, such as salt formed in a playa. Gypsum is an evaporite formed of calcium and sulfate.

fault: A fracture or fracture zone in which the sides have been displaced relative to one another. Earthquakes occur along faults.

flowing well: An artesian well under sufficient pressure to discharge water on the land surface.

focused recharge: Groundwater recharge in locations where surface water has accumulated in depressions or low-lying areas. Examples: recharge from a pond, playa, lake, or stream.

fouling: An accumulation of unwanted material on surfaces that inhibits function. It may consist of bacteria or inorganic corrosive reactions with the environment, such as rusting.

gamma ray: A very high-energy, high-speed particle emitted from an atomic nucleus during radioactive decay. Gamma rays have more energy than beta particles and can penetrate most materials. They are slowed by lead. See *alpha particle* and *beta particle.*

geochemistry: The study of the chemical composition of the earth and the chemical processes and reactions that govern the composition of rocks, water, and soil. Isotope geochemistry focuses on the elements and their isotopes in the earth; aqueous geochemistry centers on the interactions of various elements in surface water and groundwater.

geologic formation: A thickness or layer of rocks having comparable characteristics, properties, and depositional settings. The thickness of different formations can vary widely over distances, and there can be variation within a formation.

gradient: The rate of regular or graded ascent or descent, or sloping upward or downward. In chemistry, it is the regular or graded change in concentration from increasing or decreasing.

granite: A coarse-grained, crystalline rock.

grout: A construction material used to fill voids and seal joints, generally composed of a mixture of water, clay, cement, and sand. Applied or placed as a thick emulsion, it hardens over time.

half-life: The length of time that the volume of a substance undergoing radioactive decay takes to decrease by half. For example, the half-life of carbon 14 is 5,730 years, meaning that after that amount of time, half of the volume of carbon 14 has decayed to nitrogen.

hardness: The quality of water containing dissolved minerals that form scale on appliances and tap fixtures. Hard water is often indicated by a lack of suds when laundering with soap.

hydrogen sulfide: A colorless gas that smells like rotten eggs. It is often the result of bacteria breaking down organic matter in the absence of oxygen. Also known as swamp gas and sewer gas, it is perceptible in concentrations as low as 0.00047 parts per million.

hydrograph: A graph showing river stages, flow, velocity, or other characteristics of water with respect to time. A stream hydrograph commonly shows rate of flow; a groundwater hydrograph shows water level.

hydrologic cycle: The movement or exchange of water between the atmosphere and earth; also known as the water cycle.

hydrology: The science dealing with the properties, distribution, and circulation of water.

igneous: The characteristic of a rock or mineral that solidified from molten or partly molten material, or magma; also applied to the process that forms such rocks. Igneous rock is one of the three main classes into which rocks are divided, the others being metamorphic and sedimentary.

iron sulfide (pyrite): A common yellow mineral that often contains small amounts of other minerals such as arsenic, gold, and copper. Pyrite is the most widespread and abundant of sulfide minerals and occurs in all kinds of rocks.

isotope: One of two or more species of a chemical element; the species have the same number of protons in the nucleus but a different number of neutrons. The isotopes of an element have slightly different physical and chemical properties.

karst: A type of topography that is formed by dissolution over limestone, dolomite, or gypsum; it is characterized by sinkholes, caves, and underground drainage.

landform: One of the features that make up the surface of the earth. Examples include broad features such as a plain, plateau, or mountain, and minor features such as a hill, valley, slope, canyon, or alluvial fan.

lithification: The process by which geologic material is converted by processes such as cementation, compaction, and crystallization.

limestone: A sedimentary rock consisting chiefly of the mineral calcite (calcium carbonate). It is the most important and widely distributed carbonate rock.

MCL: The maximum contaminant level, or the concentration of a contaminant that is allowed in drinking water. This level is set to protect human health. Concentrations above the MCL are considered a health risk. Public drinking water providers must deliver water that meets MCLs or face enforcement measures by the EPA.

metamorphic: The characteristic of any rock derived from preexisting rocks by mineralogical, chemical, and/or structural changes, in response to change in temperature, pressure, and chemical environment, generally deep in the earth's crust.

mg/L (parts per million): Milligrams per liter. Just as percent means out of a hundred, so parts per million or ppm means out of a million. This measure usually describes the concentration of something in water.

NAPL (non-aqueous phase liquid): an oily liquid that does not mix readily with water and flows separately from groundwater. Examples are chlorinated solvents and petroleum products. A dense NAPL (DNAPL) is denser than water and tends to sink once it reaches the water table. A NAPL that is less dense than water (LNAPL) tends to float on the water table.

organic: Originating from living or previously living things, and containing carbon.

pH: A measure of the concentration of hydrogen ions in a solution that describes whether it is acidic or alkaline (basic). pH is measured on a scale that ranges from 0 (very acidic) to 14 (very basic).

pCi/L (picocuries per liter): The curie is a standard measure for the intensity of radioactivity in a sample of radioactive material. A pico denotes a factor of 10^{-12} or 0.000000000001.

parent material: The geologic material—mineral or organic—from which soils and sediment develop. Granite is a typical parent material from which sand is derived by erosion.

permeability: In fluid mechanics and earth science, the ability of a material to allow fluids to pass through it.

physiographic province: A region or province in which the landscape reflects a unified geologic history of depositional and erosional processes. Each physiographic province is distinguished by characteristic climate, vegetation, geologic structure, and rock and soil types. The elevations and shapes of a landform contrast significantly with those of nearby landforms.

playa: A dry, barren area in the lowest part of an undrained desert basin; it is underlain by clay, silt or sand, and commonly by salts. It may be marked by an ephemeral lake.

plume: In groundwater, the form that contaminants take after being discharged underground. The contaminants are diluted when they mix with groundwater as it flows downgradient.

porosity: The measure of void (empty) spaces in a material.

radioactive: Said of a material that decays as the atomic nucleus loses energy by emitting ionizing particles (radiation). The atom decays without any physical interaction with another particle from outside the atom.

reagent: A substance or compound that is added to a system to bring about a chemical reaction, or that is added to see if a reaction occurs.

recharge: The process by which water is added to a groundwater source, typically by percolation through the soils. Also, the amount of water added.

rift valley: A valley that has developed along a rift caused by geologic faulting.

rule of capture: The doctrine and its interpretation in Texas that groundwater essentially belongs to the landowner once it has been captured by a well and delivered to the surface.

SMCL (Secondary Maximum Contaminant Level): The recommended contaminant level, or concentration of a particular contaminant constituent, set to meet aesthetic standards of taste, odor, or color. Concentrations above the SMCL are not considered a human health risk.

Safe Drinking Water Act: The main federal law that ensures the quality of Americans' drinking water. Under the act, the EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers that implement the standards. The law helps protect drinking water and its sources: rivers, lakes, reservoirs, springs, and groundwater wells. It does not regulate private wells that serve fewer than 25 people.

scale: A hard residue that results from the precipitation of minerals composed of calcium and magnesium carbonates. It commonly coats the inside of water pipes and appliances.

sedimentary: Of rock created by the consolidation of sediment. Sediment forms in layers such as mud and sand.

shale: A fine-grained sedimentary rock formed by the compaction of clay, silt, or mud.

shared well: A domestic well that serves water to more than one but less than 15 connections or 25 residents. In Texas, a shared well is exempt from regulation.

soft water: Water that contains mostly sodium or potassium ions. Hard water can be "softened" by replacing dissolved calcium and magnesium with sodium or potassium ions using a water softener system. Water naturally low in total dissolved solids is also called soft water.

subsidence: The sinking of the earth's surface caused by natural geologic processes such as compaction or by human activity such as mining or pumping of oil or groundwater.

Superfund: A program of the federal government to clean up uncontrolled hazardous waste sites.

TDS: Total dissolved solids. A measure of the minerals and chemicals dissolved in water, typically recorded in milligrams per liter (mg/L).

tectonic: Pertaining to the processes and structures dealing with the broad architecture of the outer part of the earth. The major structural or deformation features and relations, origin, and historical evolution of the earth.

topography: The general configuration of a land surface, including its elevation relief and the position of its natural and manufactured features.

transpiration: The process by which water vapor is lost to the atmosphere from living plants.

unconfined (confined): Said of an aquifer that receives recharge directly from the land surface. It is sometimes also called a water table aquifer because its upper boundary is the water table.

unconsolidated: Said of sediment that is loosely arranged, unstratified, or made of particles that are not cemented together.

VOC (volatile organic chemical): Organic, carbon-based chemicals that vaporize easily or evaporate at room temperature.

volcanic: Pertaining to the activities, structure, and rock types of a volcano.

water cycle: The movement or exchange of water between the atmosphere and the earth; it is also called the hydrologic cycle.

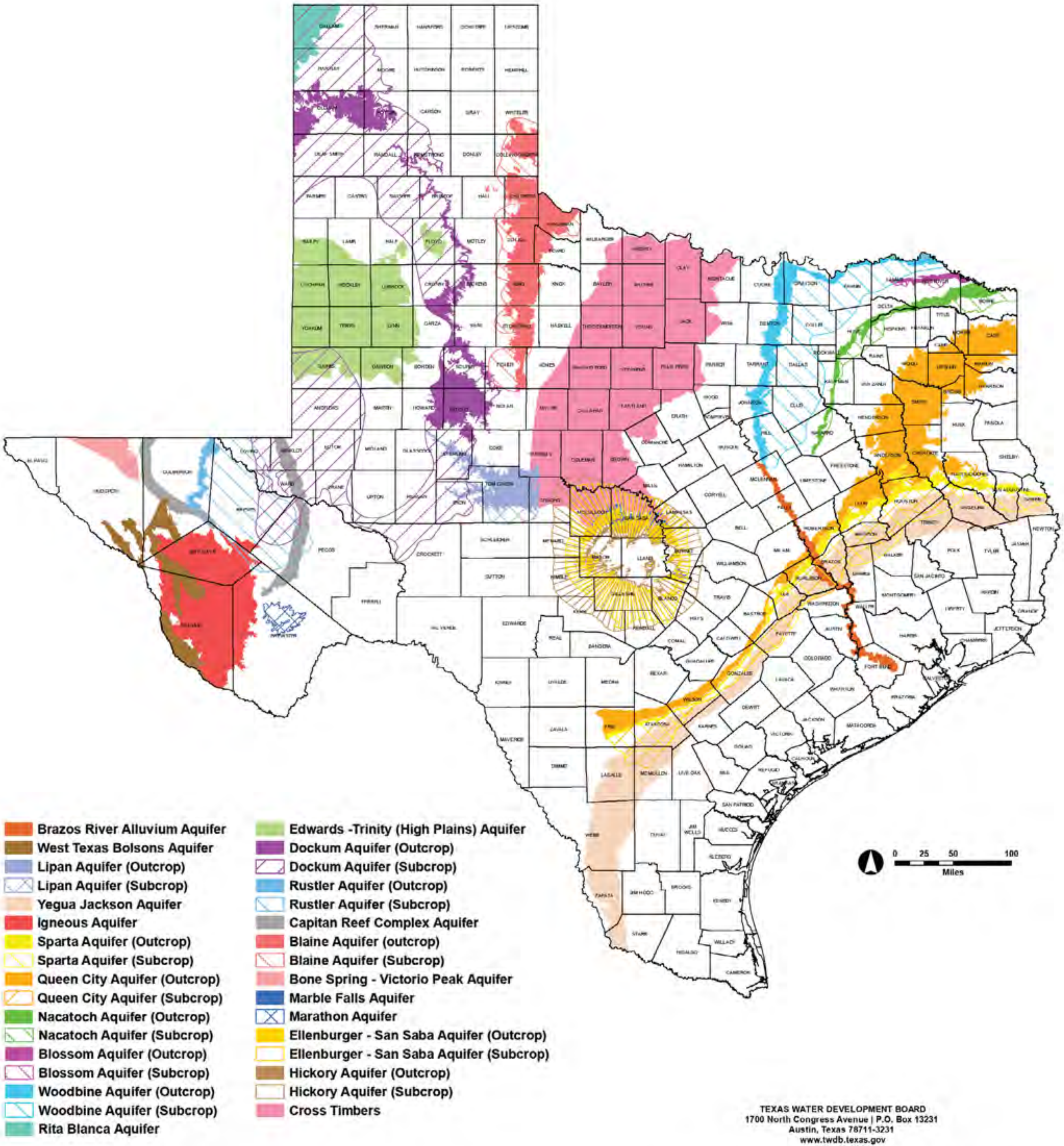
watershed: A land area that drains to a common waterway such as a stream, lake, wetland, or ultimately the ocean.

water table: The surface between the saturated and unsaturated portions of an aquifer.

weathering: The destructive processes by which rocks are changed on exposure to atmospheric agents at or near the earth's surface; the physical disintegration and chemical decomposition of rock that produces sediments.

well development: The process of over-pumping a well after it has been constructed to ensure that it is connected to the aquifer. It removes fine-grained sediments from the borehole and alters the physical characteristics of the aquifer near the borehole to enable water to flow more freely to the well.

Minor aquifers of Texas.



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- Aquifer chronology by geologic age.
- Solid colors indicate OUTCROP areas (portion of a water-bearing rock unit exposed at the land surface).
- Hatch colored lines indicate SUBCROP areas (portion of a water-bearing rock unit existing below other rock units).
- The Edwards-Trinity (High Plains) Aquifer and the Rita Blanca Aquifer are both entirely subsurface.

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