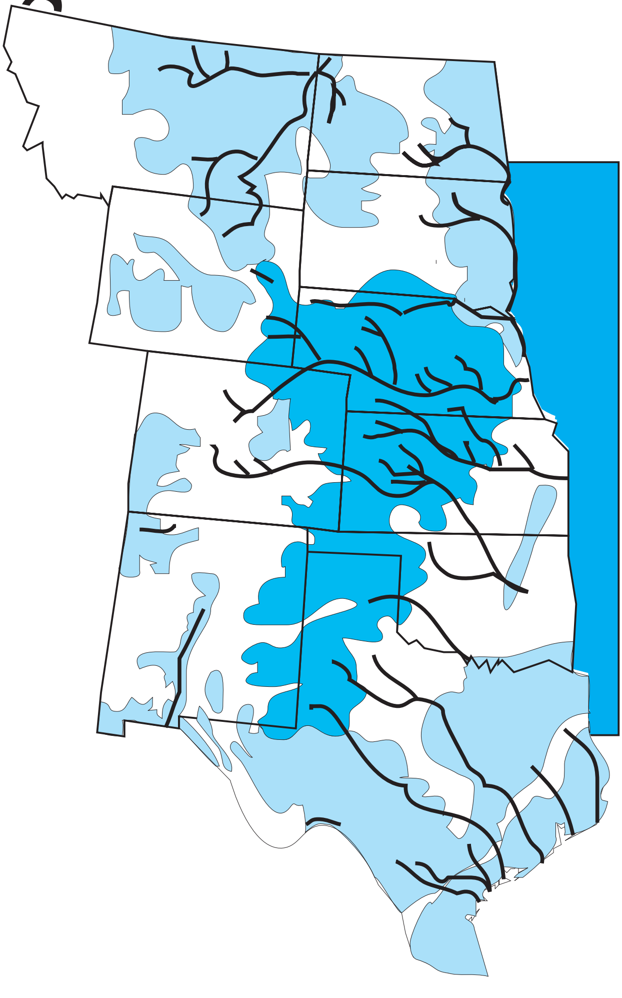
A Publication of the
Great Plains
Agricultural Council

groundwater IN THE GREAT PLAINS



GPAC Report 141

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Author's Note

This primer was developed by the Texas Water Resources Institute at Texas A&M University for the Great Plains Agricultural Council. The Council serves a forum to study and discuss a variety of agricultural and natural resources issues in the region.

The primer was first published in 1991. It is now out of print.

This project was coordinated by TWRI Director Wayne Jordan. The text for the primer was written by TWRI Information Specialist Ric Jensen, in consultation with many experts at universities in the region. The vast majority of the text has not been changed substantially from the original version, although some information has been updated.

Originally, graphics for the primer were developed by Reagan Johnson, Mark Barnes, and Enrique Flores, who were TWRI student workers at the time. The updated graphics you see in this version were developed by TWRI student workers Tung Tran and Jason Middleton.

We hope you find the primer to be useful, fun, and informative. Contact us at twri@tamu.edu if you have any comments or questions.

Introduction

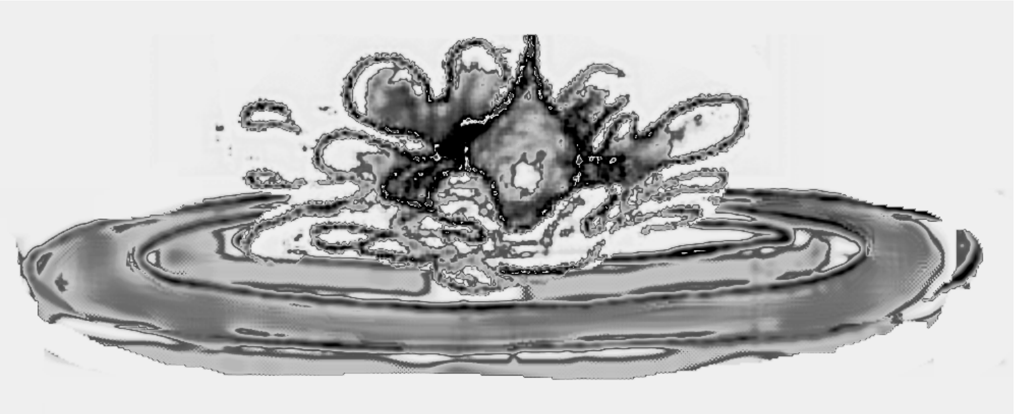
Groundwater lies hidden beneath the soil, out of sight and largely out of mind. As a result, it's poorly understood by most who depend on it for drinking water and other uses. Misconceptions about groundwater are common. In 1904, a Texas judge ruled that "the existence, origin and movement of (ground) water...is so secret, occult and concealed...(that) any attempt to administer any set of legal rules in respect to it would be involved in hopeless uncertainty." In spite of increasing scientific knowledge, groundwater is still perceived in much the same way by the public today.

Despite the lack of understanding, groundwater is the most significant water resource for most Americans.

Roughly 75% of U.S. cities depend on groundwater for all or part of their water supplies. More than half of all Americans and 95% of all persons in rural areas rely on groundwater as their primary source of drinking water.

Throughout the United States and the world, vital aquifers supply irrigation and drinking water for many regions More than 97% of the world's usable freshwater supply – an estimated 9 trillion acre feet – is groundwater.

Despite the seeming abundance of groundwater, there are concerns about how long its supplies will last, especially in areas where water use is high, and whether its quality is being threatened by natural and man-made contaminants.



The Great Plains contains some of the most abundant groundwater systems in the world. Much of the groundwater comes from the High Plains Aquifer, which is also known as the Ogallala Formation. This massive aquifer stretches from South Dakota to Texas and also supplies water to Wyoming, Colorado, New Mexico, South Dakota, Nebraska, Kansas and Oklahoma.

Groundwater in the Great Plains

Protecting Groundwater Quality

Protecting groundwater quality poses special problems. For example, when a river, lake or stream is contaminated with algae or an oil spill, it's apparent that water quality has been degraded. Motorists who drive by notice it, boaters and swimmers come in contact with it, and fish and wildlife may be obviously affected. However, because we don't come in contact with groundwater on a regular basis, and because we rarely if ever see it, the only way we can suspect if contamination has taken place is if our water looks, tastes, or smells differently. Even if everything seems OK, we won't know for sure until the water's been tested. As a result, groundwater quality degradation has often been ongoing for some time before it's detected.

These same problems also hinder cleanup efforts. When surface waters are polluted, it's a fairly straightforward process to identify which areas need to be cleaned up. In the case of groundwater, we can't see where the contamination is located and how widespread the problem is. Even after the scope of the problem has been determined, removing contaminants and restoring groundwater quality is often time-consuming and expensive, if not impossible.

In productive farming areas such as the Great Plains, use of agricultural pesticides and fertilizers may cause contamination from nitrate and complex organic chemicals.

Other potential sources of groundwater pollution include leaking underground storage tanks, dumps and landfills, septic tanks and drainfields, oil and gas exploration activities, wells used for the injection of hazardous wastes, and wastewater treatment systems. Abandoned and improperly constructed wells also provide pathways for pollutants to enter groundwater systems.

Even in rural areas, agricultural practices are not the only sources that threaten water quality. In some regions, rocks and soils contain naturally high levels of soluble minerals such as sodium, nitrate, and chloride. Groundwater often accumulates soluble minerals as it percolates downward from the surface.

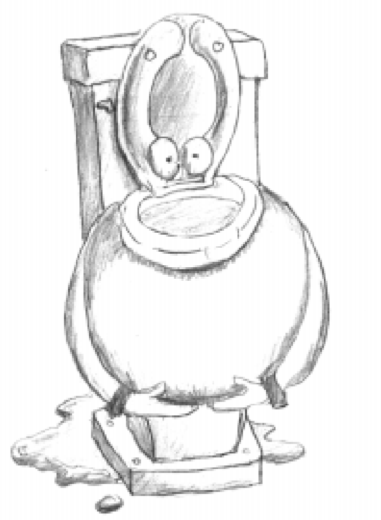
In some areas, the underlying geology also influences contamination risks. In some areas, cracked and fissured rocks create a direct pathway for surface contaminants to flow virtually unimpeded into groundwater supplies. Sandy soils also allow contaminants to easily flow through them to reach groundwater quickly with little or no dilution.

In the future, the amount of groundwater we will be able to utilize for drinking water, irrigation, and other purposes, may be affected by how well we protect it from contamination

Although the problem of protecting groundwater, both from a quantity and quality standpoint, seems imposing, there are some promising solutions on the horizon.

Keeping Groundwater Pure and Plentiful

Irrigation systems and improved crop management strategies have been developed which allow farmers to use less water and agricultural chemicals and may extend groundwater supplies while minimizing pollution risks. New strategies called "integrated crop and pest management" control insects and plant diseases with a combination of natural and biological controls and traditional agricultural chemicals. These technologies greatly reduce the amount of chemicals that are introduced into the environment. Agricultural producers and urban residents are more aware that overuse and improper disposal of fertilizers and pesticides can harm the environment. More safe underground storage tanks and landfill liners that have been designed to resist leaks are being installed in many areas. Less household waste is being sent to landfills and more emphasis is being given to recycling and safe disposal programs.



An efficient toilet uses only 1.6 gallons per flush (gpf), while an average toilet uses 3.5 to 7 gpf. This is a waste of 18,108 gallons and $91 annually for a 3-person household.

Safe use and disposal of household chemical wastes can protect water quality. Citizens can take part in wellhead protection programs to safeguard drinking water wells.

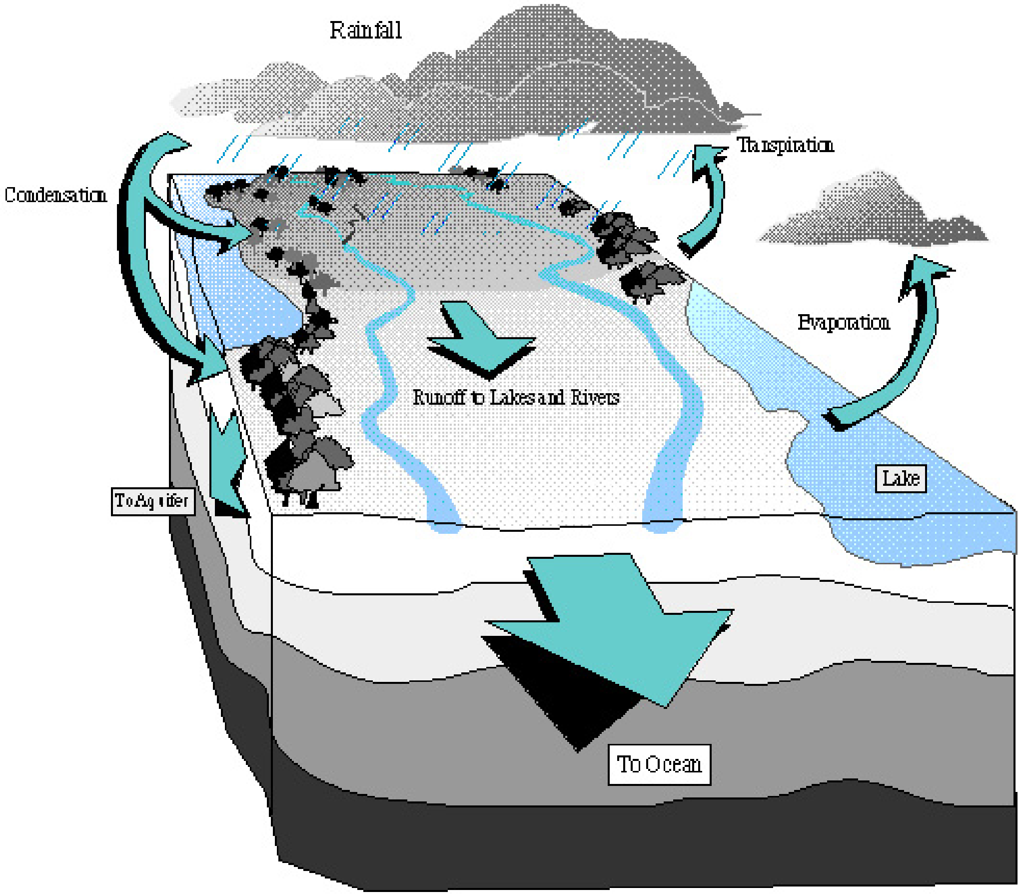
The Importance of Conservation

Conservation programs can dramatically reduce both rural and urban water use. For example, household water use can be cut by 60% through the use of low-flow toilets, showers, and other water-efficient appliances. Outdoor water use for watering lawns and gardens can be dramatically lowered through "xeriscaping" —the use of water-efficient landscape plants and irrigation management strategies.

	Residential				**Landscapes**	**Commercial**	**Agricultural**
	Toilets	Showers	Washing Machines	Dishwashers	Lawn Irrigation	Toilets	Sprinkler Systems
Per Capita Avg. Use Rate	4 flushes per day	4.8 min. per day	0.3 loads per day	0.2 loads per day	not available	3 flushes per day	not applicable
Without Conservation	5.5 gallons per flush	3.4 gallons per min.	55 gallons per load	14 gallons per load	10,000 gallons per day per residence	6 gallons per flush	40 to 80% efficiency
With Conservation	1.5 gallons per flush	1.9 gallons per min.	47 gallons per load	8.5 gallons per load	5,000 gallons per day	1.5 gallons per flush	75% to 95% efficiency
Savings	63%	45%	15%	40%	50%	75%	15 to 35%

What is Groundwater?

The first question that needs to be answered is, "Where does groundwater come from?"



The Hydrologic Cycle

Groundwater, like all other forms of water, is part of the **hydrologic cycle**. Water is lost to the atmosphere by evaporation and plant use (transpiration) and returns to soils, aquifers, lakes, and rivers as rain or snow. The water that falls on the soils and percolates through them becomes groundwater. **Infiltration** refers to the process by which water enters into soils. Downward movement of water through soil by gravity is called percolation. Together, infiltration and **percolation** determine the potential quantity and rate of water movement from the surface to the aquifer or water table.

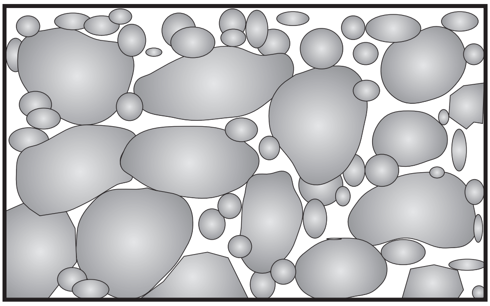
Recharge refers to percolating water that replenishes groundwater. Most recharge occurs through precipitation. Sites where significant amounts of recharge occur (typically areas with coarse or fissured soils including sinkholes, caverns, and lake and stream beds) are termed **recharge zones**. Special precautions need to be taken to prevent contamination from taking place in recharge zones because pollutants can easily reach groundwater systems in these areas. Recharge can be either natural or artificial. Artificial recharge projects divert water underground and are usually most effective in areas with high infiltration rates. Techniques that are commonly used include spreading basins, recharge dams, and injection wells.

Groundwater Flow Patterns

Groundwater and surface water resources are interconnected. Streams, lakes, and springs are often fed by groundwater, which provides 30% of river and stream flows. During prolonged dry periods, water losses from groundwater systems may account for almost all of a stream's base flow.

In some cases, the ground-surface water connection is pronounced. Rivers and streams flowing over karst or limestone formations recharge aquifers which in turn replenish downstream springs and rivers.

When many people first think of groundwater, they imagine streams, rivers, and lakes that occur underground. That's rarely the case. Groundwater fills the spaces, pores, and cracks between rocks, gravel, sands, and fine particles.



Sand and gravel formations are highly porous and highly permeable.

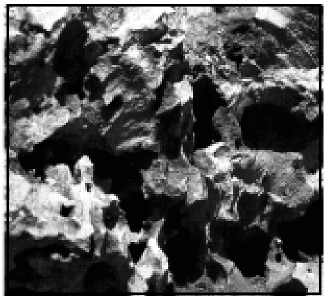
Groundwater does flow, although unlike rivers and streams, it typically travels very slowly. Depending on flow rates, pumping, and depth, that rate or residence time can range from as little as a few days to as long as 10,000 years. The slow movement also dictates that little mixing occurs. An implication is that contaminants entering aquifers might not be diluted as rapidly as they would in rivers and streams.

Like surface water, groundwater normally flows from higher to lower elevations. The point at which waters exit the groundwater system is referred to as **the discharge point**. Natural discharge points include springs, artesian wells, and streams. Wells for irrigation and public water supply are major man-made discharge points. Flow patterns near discharge points often differ from natural flow patterns.

Saturated and Unsaturated Zones

Soil and rock formations beneath the earth's surface are divided into unsaturated and saturated zones. In the unsaturated zone (also known as the vadose zone or zone of aeration) air and water fill the spaces around rocks and soil particles. This permits plant roots and organisms to grow there. In the uppermost portion of the unsaturated zone called the root zone or shallow vadose zone, soil water is used by crops or percolates downward. This is the most important zone for crop production. The capillary zone lies between the unsaturated zone and the water table. Water is held between individual soil particles in this zone. In the saturated zone, all pores or cracks are filled with water.

Porosity and permeability are two geologic properties of groundwater formations that greatly influence how much water a groundwater system can contain and how fast water and contaminants move through it. Porosity is the amount of open space a formation contains. In sand and gravel deposits, it depends on the size and shape of the crevices or cracks. Other rocks like sandstone and limestone are natural porous.

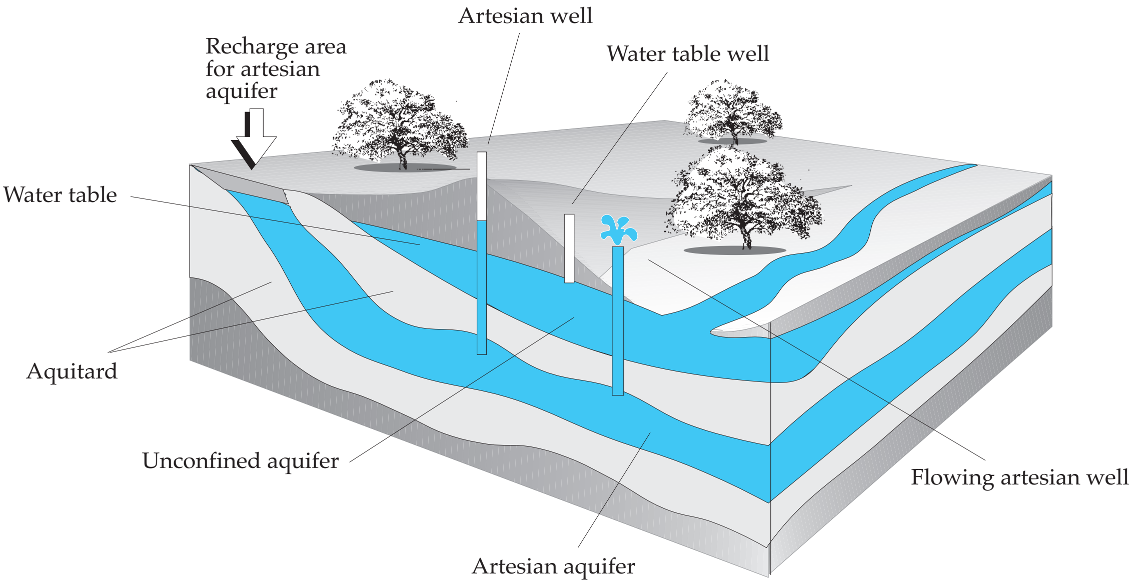


Limestone from a karst aquifer exhibits low porosity and high permeability.

Permeability is the ability of fluids like water to travel through the medium. Sand and gravel aquifers are highly porous and highly permeable. Karst aquifers are comprised of fractured and fissured limestone and exhibit low porosity, but high permeability. Clay aquifers have high porosity but low permeability. As a result, clay aquifers usually don't yield and transmit large amounts of water.

Aquifers

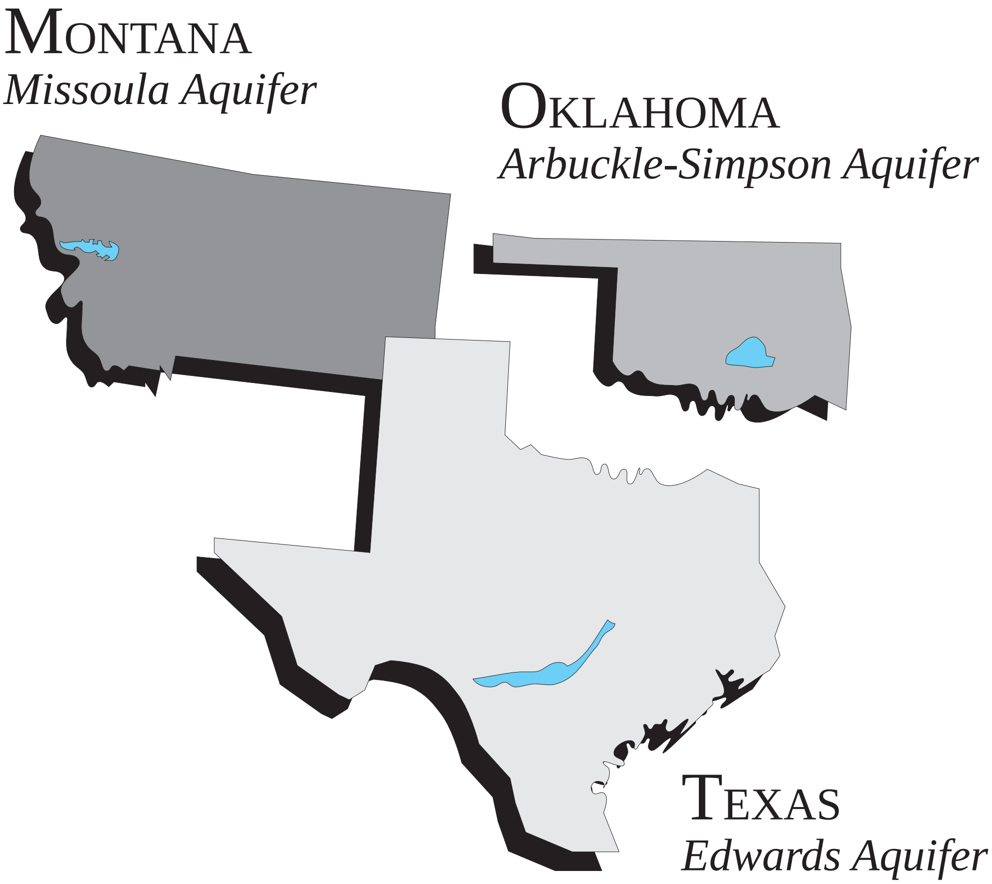
Two types of aquifers are most common. In **unconfined or water table aquifers**, the groundwater is in direct contact with the unsaturated zone and the atmosphere. As a result, groundwater levels fluctuate with changes in atmospheric pressure and with changes in the amount of water stored in the aquifer. Unconfined aquifers such as the Ogallala Aquifer provide water to wells by draining groundwater formations that surround the well. This drainage occurs under the force of gravity and removes water from large pore spaces. Often 30 to 40% of the groundwater may remain after wells no longer yield water. Most **alluvial aquifers** are unconfined and often form along or beneath stream and river beds. Alluvial aquifers often produce large amounts of water, because they are recharged by infiltration from nearby streams.



Confined or artesian aquifers are contained between layers of impermeable material called **aquitards** that prevent the free movement of water. **Aquitards** are layers or formations with low permeability. They often contain water but do not typically produce large well yields. Perched water tables are isolated pockets of groundwater that are usually separated from the main portion of the aquifer by clay lenses or other materials water can’t easily penetrate. They are often temporary, forming after periods of heavy infiltration (storms or snowmelt) and disappearing when the infiltration diminishes. Often, perched water tables don’t yield large amounts of water over a long time period.

Only groundwater systems that produce enough water to produce enough water to provide a usable supply of water are called aquifers. There is no precise definition of how much water must be present to define a groundwater system as an aquifer. In general, most aquifers occur within 2,500 of the earth's surface.

Sole Source Aquifers



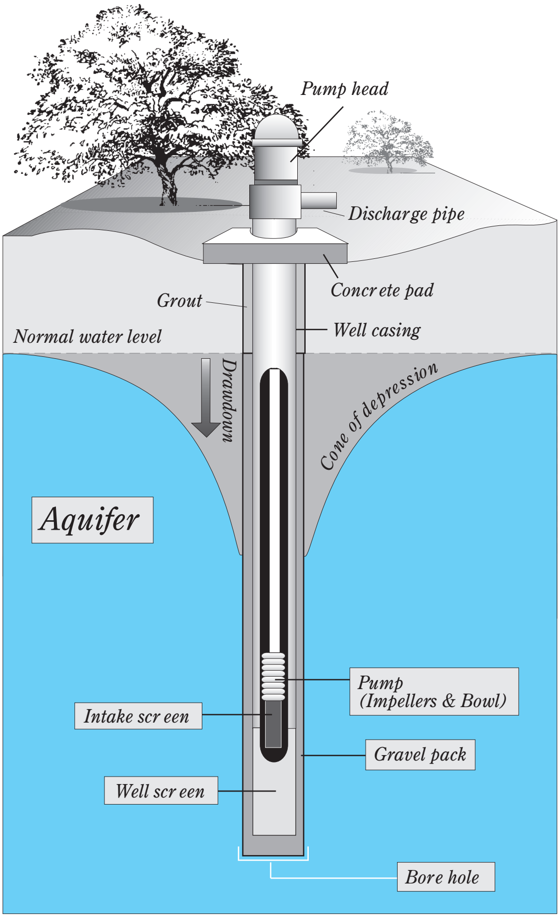
Sole source aquifers are provided special protection under Federal law. They are specifically designated by the Safe Drinking Water Act as groundwater systems of critical importance or are the only major supply of drinking water for a specific region. The sole source aquifer program is intended to reduce pollution risks from any Federally funded project.

Sole source aquifers in the Great Plains region include the Edwards Aquifer in Texas, the Arbuckle-Simpson Aquifer in Oklahoma, and the Missoula Valley Aquifer in Montana.

Water Wells

Water wells capture groundwater and transport it to the surface where it can be utilized. Most modern wells are drilled by truck-mounted cable-tool, air, or hydraulic drill rigs. Driven wells can be installed by hand or with power equipment and are still common where geologic conditions permit.

A properly designed and installed well includes a number of components including the pump, well casing, gravel pack and screen. Many states require wellhead protection structures to prevent water from reentering and polluting aquifers. These typically include a concrete pad and the use of concrete or other types of grout to seal the space between the well casing and other edge of the borehole between the surface of the ground and the water table. The casing is a conduit through which water is transported to the surface. The casing is usually steel or plastic and is constructed in two sections: a solid pipe and a pipe with very small slots referred to as the well screen.



The gravel pack may be composed of particles ranging in size from small gravel to very fine sand. The size of these particles and the slots in the well screen are based on a particle size analysis of the surrounding aquifer material. These are designed to prevent soil and sand from entering the pump.

The amount of water that can be obtained from any groundwater system depends greatly on the permeability and the extent and thickness of the aquifer. Shallow wells may provide adequate amounts of water when very permeable materials are near the land surface. An indication of the amount of water that can be taken from an aquifer can be derived from **pumping tests**. **Well yields** refer to the amount of water that can be pumped over a given time.

Pumping often lowers the water level immediately around a well. This is commonly referred to as a **drawdown** and forms a **cone of depression**. If the rate of pumping is greater than the rate of water movement in the aquifer, the cone may extend to other nearby wells and may also lower water levels in those areas. **Pumping lift**, the distance groundwater must be pumped to reach the surface, increases as aquifers are depleted.

When the amount of groundwater that is pumped exceeds recharge rates over long periods of time, **aquifer depletion** or **mining** can result. Many aquifers are now being depleted including parts of the High Plains Aquifer in Texas, Oklahoma, Colorado, Kansas, and Nebraska.

Groundwater Quality

How can we measure groundwater quality? How can we tell if an aquifer contains contaminants and pollutants at potentially harmful levels?

Contamination and Pollution

To understand processes that affect groundwater quality, a few principles need to be explained. **Contamination** refers to physical, chemical, biological, or radiological constituents that degrade water quality. **Impairment** refers to water quality that has been degraded so that it's unfit for a specific use. Water may be so salty that it's impaired for use as drinking water, but it could still be used to irrigate salt-tolerant crops or for some industrial purposes. **Pollution** occurs when water quality has been degraded in excess of established regulatory guidelines. Water with substances in excess of levels allowed by the Safe Drinking Water Act, the Clean Water Act, or other regulations is referred to as polluted. Contamination, impairment, or pollution can all result from natural conditions or man's activities.

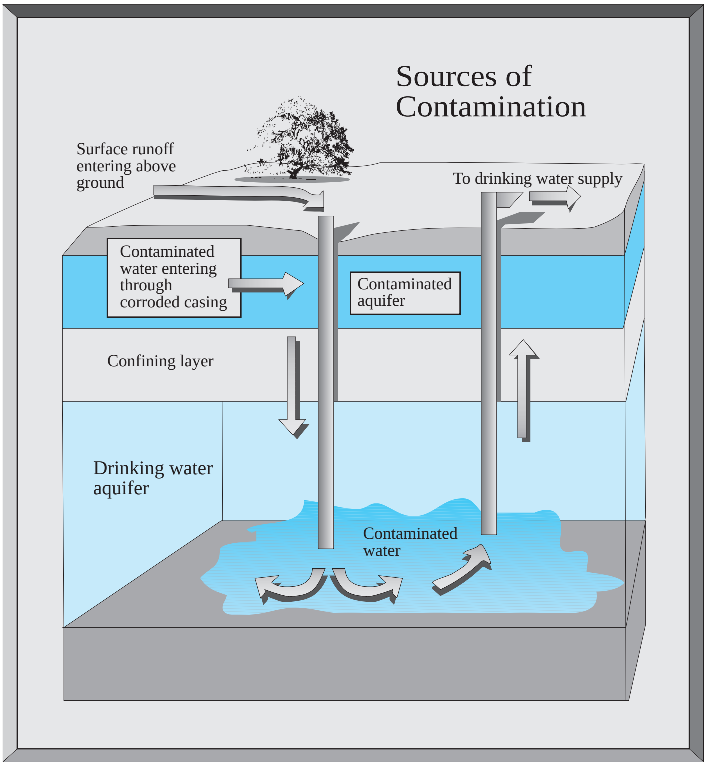
Measuring Contaminants

Measuring groundwater quality depends on how well we can detect and identify the contaminants that are dissolved in the water.

All groundwater contains some dissolved salts or other soluble substances. In general, the chemical composition of naturally occurring constituents mirrors the composition of the rocks and soils the water has passed through. Chemical concentrations typically increase as the water travels along its flow path because it reacts with the rocks and minerals that comprise the aquifer along the way. In arid areas, high rates of evaporation and transpiration often increase levels of dissolved salts, making the water more saline.

In most of the United States, salinity increases at greater depths in an aquifer. Waters also collect organic matter and carbonic acids, which are produced when plant roots respire and plant residues decay. If there are excess amounts of calcium and magnesium, **water hardness** results. Hard water leaves deposits and scales inside pipes, shower heads, faucets, and fixtures, making hot water systems less efficient and more expensive.

Although fractured and fissured soils can increase the likelihood of contamination, other soils and the microorganisms that live in them can actually reduce contamination risks. Bacteria and fungi can degrade some contaminants, often converting them into less harmful by-products.



Factors That Affect Contamination

Many other factors influence interactions between soils, chemicals, and water quality. **Water solubility** is the ability of a chemical to dissolve in water. Generally, the probability that a chemical may reach groundwater increases as solubility increases. **Persistence** refers the ability of chemicals to survive in their natural form in soils and the environment. Often, it's referred to in terms of the **half-life** of a chemical – the time it takes for natural processes to degrade a chemical to half its concentration or potency. **Adsorption** refers to the ability of some chemicals to bind to soils and thus limit their downward movement.

Clay particles and soil organic matter are important soil components affecting absorption. Contaminants that are bound to soil particles pose less of a threat to groundwater quality than those that are free to move. **Leaching** is the process by which substances are dissolved in water and move downward through soils into groundwater systems. Dissolved and suspended minerals, fertilizers, and other chemicals can all leach into groundwater formations, but do so at different rates.

Parts per Quadrillion

Over the past 25 years, advances in analytical techniques have enabled scientists to detect contaminants in smaller and smaller amounts. Many regulatory standards are now expressed in terms of **parts per million** or **parts per billion**.

One part per million is equivalent to dissolving pound of sugar into 120,000 gallons of lemonade. One part per billion means that there is one ounce of a pollutant dissolved in a billion ounces or 120 million gallons of water. Now scientists can measure amounts as small as parts per trillion or parts per quadrillion. Trying to find a part per quadrillion has been compared to finding a postage stamp in an area as big as the states of New Mexico, Nebraska, and South Dakota combined.

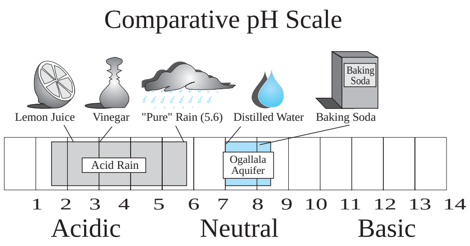
Background Water Quality

Background conditions refer to the pre-existing condition of a groundwater system that has not been altered by human activities. Almost all groundwater contains some levels of natural contaminants including sodium, calcium, magnesium, chloride, and many other minerals. In other words, no aquifer contains "pure" water. In some cases, "natural" contamination may be severe enough to limit the use of the aquifer. Background water quality provides a benchmark that can be used to compare the original water quality to present conditions.

Naturally Occuring Contaminants

Contaminant	Source or Cause	Significance
Silica	dissolved from rocks and soils	forms scales on pipes
Iron	dissolved from rocks and soils	in groundwater iron may oxidize and cause taste and odor problems
Calcium and Magnesium	dissolved from rocks and soils, mainly limestone and gypsum	causes hardness and forms scales
Sodium, Chlorides and Potassium	dissolved from rocks and soils	large amounts can give water a salty taste; high sodium can limit use for irrigation
Bicarbonate and Carbonate	action of carbon dioxide in water on limestone	can produce alkalinity, hardness and scale formation
Sulfate	dissolved from rocks and soils containing gypsum and sulfur	can produce scaling problems and give water a bitter taste
Fluoride	dissolved from most rocks and soils	reduces levels of tooth decay; excess may produce mottled teeth in children
Nitrate	decaying organic matter; dissolved from rocks	makes water taste bitter; can lead to "blue baby" syndrome
Dissolved solids	minerals dissolved from rocks and soils	may make water unfit for drinking
pH	acids and acid generating salts lower the pH; carbonates, bicarbonates, and phosphates raise pH	corrosiveness of the water increases as pH decreases
Boron	found in rocks and natural formations	high levels make water toxic and unusable for irrigation

Naturally Occurring Contaminants



Although many people perceive that man's activities are the major source of groundwater contamination, many studies suggest that **naturally occurring contaminants** are a major source of groundwater quality degradation. For example, a recent report concluded that roughly 60% of groundwater systems in the United States would violate at least one component of the Safe Drinking Water Act because of excessive levels of naturally occurring contaminants.

Naturally occurring chemicals that can be leached into aquifers include nitrate, selenium, iron, silica, sodium, potassium, fluoride, boron, mineral salts, radioactive materials, and toxic substances.

The acidity or alkalinity of waters (measured as pH values) may also be impacted by natural and introduced contaminants. The pH scale ranges from 1 to 14. A value of 7 is neutral, scores below 7 are acidic, and values above 7 are alkaline. Typical values in the High Plains Aquifer range from 7 to 8.

Man-Made Pollution

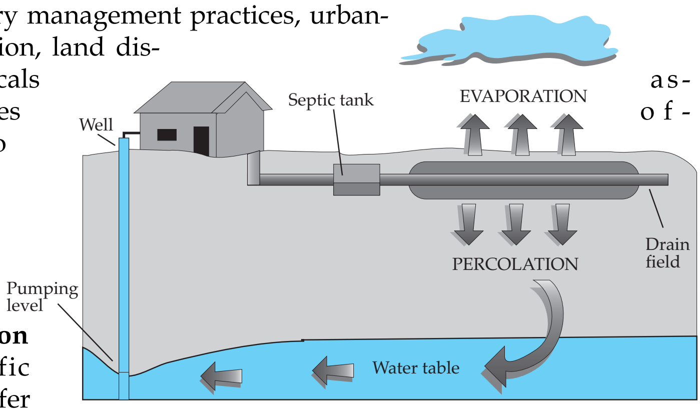
Man-made pollution can originate from a number of activities including the use of agricultural chemicals, waste disposal, leaking underground storage tanks, city dumps and landfills, on-site wastewater systems, oil and gas exploration activities, wells used for the injection of hazardous wastes, and municipal wastewater treatment systems.

Disposal of common municipal and domestic wastes can endanger groundwater quality. **Septic tanks and drainfields** sited above shallow aquifers can introduce contaminants such as fecal bacteria, viruses, household chemicals, nitrate, and organic solvents. Toxic and hazardous chemicals have been found leaching from beneath municipal dumps or **landfills** into groundwater systems.

Point and Non-Point Source Pollution

Non-point source pollutants are diffuse and do not have a single point of origin. Common non-point source pollutants that impact groundwater systems are produced by agricultural and forestry management practices, urbanization, mining, construction, land disposal, and erosion. Chemicals associated with these practices often leach downward into aquifers. Non-point source pollutants can also be carried off the land by stormwater runoff to rivers and lakes.

Point source pollution originates from specific sources or reaches the aquifer by a direct path. Agricultural chemicals that are poured into a fractured or creviced opening over a limestone aquifer and reach a groundwater source relatively unchanged are an example of point source pollution. Other typical cases include pollutants that enter aquifers through abandoned wells, wastewater treatment plants and industries that discharge directly into a river or stream, and landfill leachate that seeps into aquifers.



How septic effluent percolates to the water table.

Agricultural Practices

Agricultural practices can also degrade groundwater quality. These include overuse and misuse of fertilizers and pesticides, manure from livestock, dairy, and poultry operations, agricultural drainage wells, and accidental spills.

Agricultural **fertilizers** usually contain **nitrogen, phosphorus**, and **potassium**, each of which may pose a contamination risk. Recent studies suggest that crops use only about 50 to 70% of the amount of nitrogen supplied by fertilizers – the remainder is excess and can lead to high nitrate levels in soils and groundwater.

Feedlots, poultry and **dairy operations** may also increase levels of **nitrate**, **phosphates**, **chlorides**, **salts**, and **fecal bacteria** in groundwater systems if animal wastes are improperly applied to the land surface.

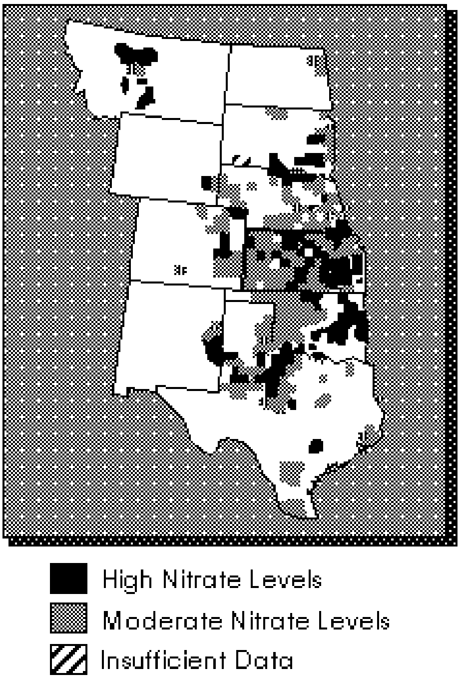
Nitrate

Nitrate is one of the most widely found groundwater contaminants and presents major concerns. Human activities that can elevate nitrate levels include septic tank wastes, sewage effluents, and agricultural sources like fertilizers and cattle feedlots. In rare cases, infants that drink water with high nitrate levels, can die from **"blue baby syndrome"** or **methemoglobinemia**.

Two recent national studies provide insights into the extent of nitrate contamination of groundwater in the region. In general, they show that there are low levels of nitrate throughout much of the Great Plains region. Areas with shallow groundwater (less than 50 feet from the surface) or aquifers below unconstructed coarse or sandy soils are the most vulnerable to nitrate contamination.

A 1987 report by the USDA/ Economic Research Service (ERS) estimated the groundwater pollution potential caused by nitrate and pesticides in groundwater systems in agricultural areas. The report utilized actual data from more than 120,000 wells. Nitrate levels were estimated (based on crop acreage and fertilizer rates) in areas where there was insufficient information. No efforts were made to separate areas with naturally elevated nitrate levels. The report estimated that groundwater supplies in 474 counties in the United States (28% of the total) contained higher nitrate levels than projected background concentrations. Roughly 25% of the wells in these counties produced water with more than 3 mg/ L of nitrate-nitrogen. Estimates of groundwater that exceeded the Safe Drinking Water Act standard of 10 mg/ L were also low. The study projected that only 85 counties were expected to have more than 25% of their wells which did not meet the standard.

Nitrate-Nitrogen
Distribution in Groundwater
in Agricultural Areas



EPA recently completed the National Pesticide Survey. It estimated that only 5% of rural domestic wells (60,000 wells) in intensively farmed counties with high pesticide use and only 2% of the wells (60,000 wells) in counties with high groundwater vulnerability exceeded nitrate-nitrogen levels of 10 mg/L. More than half of all wells contained detectable levels of nitrate, but the concentrations were typically far below established health standards.

A 1987 Nebraska study collected data on nitrate and pesticide levels from 5,826 wells. About 20% of the wells had nitrate-nitrogen concentrations above 10 mg/L. Wells used for irrigation were more likely to contain excess nitrate levels than wells used for public supplies, rural drinking water, or livestock. Irrigated areas with well-drained soils and water tables less than 50 feet deep were most vulnerable to contamination. Irrigated crops require more nitrate and water used for irrigation can move nitrates below the root zone to the water table. A 1991 Nebraska study involving 3,900 fields where irrigated corn is grown found a strong correlation between nitrogen fertilizer applications and nitrate levels in groundwater. Results could be similar from other Great Plains states with like hydrology and farming practices.

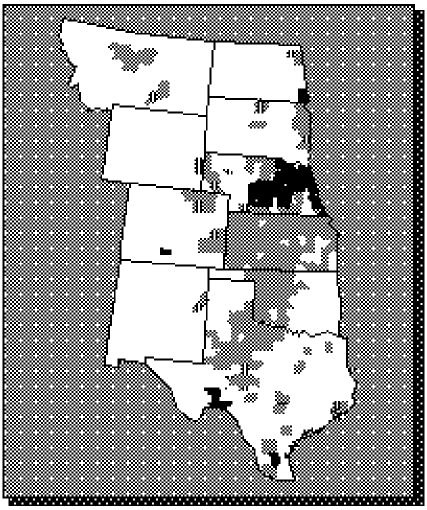
However, not all nitrate contamination is due to heavy use of fertilizers. Groundwater in the Texas Rolling Plains was known to contain high nitrate levels as early as the 1950s, before any appreciable amounts of nitrogen fertilizer were used. In this case, nitrates probably originated from the breakdown of soil organic matter when land was cultivated.

Pesticides

There are more than 50,000 **pesticides** (including herbicides, insecticides, fungicides and other agricultural chemicals) licensed for use in the United States. An estimated 1.1 billion pounds of pesticides are used nationally each year. Many isolated incidents have been reported where agricultural pesticides such as ethylene dibromide, aldicarb, arsenic, atrazine, bromacil, dacthal, and others have contaminated groundwater.

The 1987 USDA/ ERS study estimated areas of potential groundwater contamination from agricultural chemicals and pesticides. Application rates were estimated for 38 pesticides with high probabilities to leach into groundwater systems, based on crop acreage and average pesticide application rates. Those pesticides account for 60% of the agricultural chemicals used in crop production. The same techniques used to assess groundwater vulnerability to nitrate-nitrogen were replicated for the pesticide study. Results suggest that roughly 33% of the counties in the United States have both high pesticide use and high groundwater vulnerability, including a large section of Texas, Nebraska, Kansas and Oklahoma that potentially could be especially vulnerable. According to the EPA National Pesticide Survey, roughly 10% of community water system wells (9,850 wells) and 4% of rural domestic wells (446,000 wells) are estimated to contain detectable levels of at least one pesticide. DCPA acid metabolites (estimated in 6,010 community water system wells and 264,000 rural domestic wells) were most common, followed by atrazine (1,570 community water system wells and 70,800 rural domestic wells) and DBCP (370 community water system wells and 38,400 rural domestic wells). The survey said 60,900 rural domestic wells were likely to contain pesticides above EPA Maximum Contaminant Levels (MCLs) and that more than 19,000 rural domestic wells exceeded EPA Health Advisory Limits for pesticides.

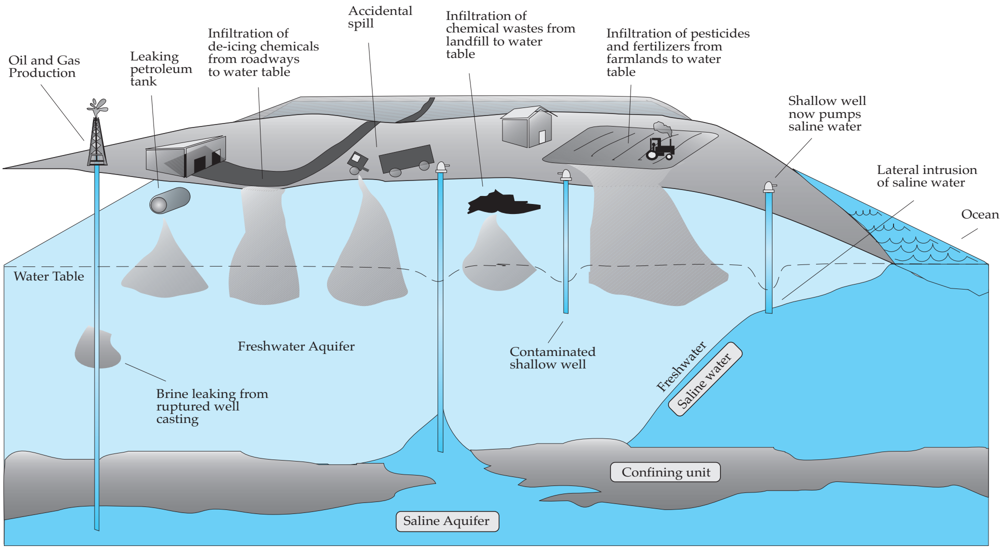
Central U.S. Areas of
Potential Groundwater Contamination
from Agricultural Chemicals



■ Nitrates and Pesticides
▩ Nitrates Only
▨ Pesticides Only

Areas with high pesticide usage and high groundwater vulnerability may have special problems, according to the pesticide survey. In counties with high pesticide use, pesticides are expected to be detected in 41,100 wells and 3,140 wells are likely to exceed the MCL for at least one pesticide. In counties with high groundwater vulnerability, 79,700 wells are anticipated to contain at least one pesticide and 6,280 wells are likely to exceed the MCL for at least one pesticide.

Mechanisms of Groundwater Contamination



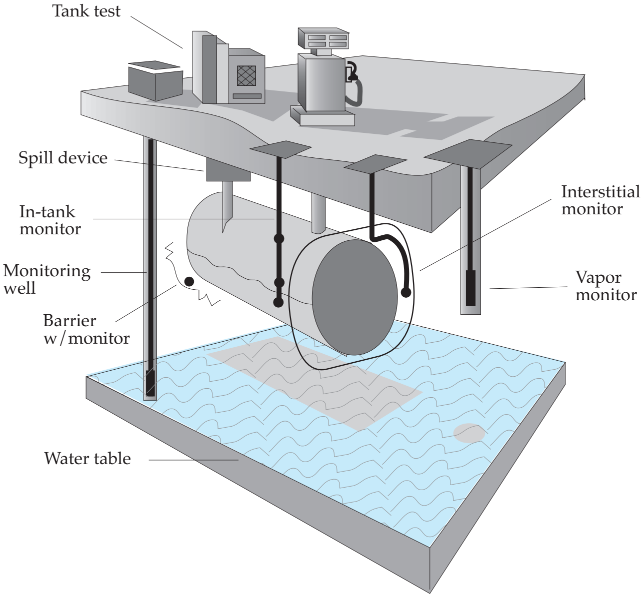
Abandoned and Improperly Plugged Wells

The construction, placement, and maintenance of water wells can all play key roles in protecting water quality. For example, corrosion can cause cracks and holes in the well casing. Gaps between the well casing and the wellhole can provide direct pathways for contaminants to pollute aquifers.

Abandoned and improperly plugged wells that once tapped aquifers for oil and gas exploration, drinking water and irrigation supplies can also be sources of groundwater contamination if they are improperly sealed or plugged.

Injection wells are often used to dispose of oilfield brine and industrial wastes, hazardous and toxic chemicals, sewage, stormwater runoff, and other materials, and can also pose a pollution risks. Injection wells can also provide pathways for pollutants to migrate from the surface or beneath the ground into aquifers used for drinking water and other purposes.

Leak Detection Alternatives



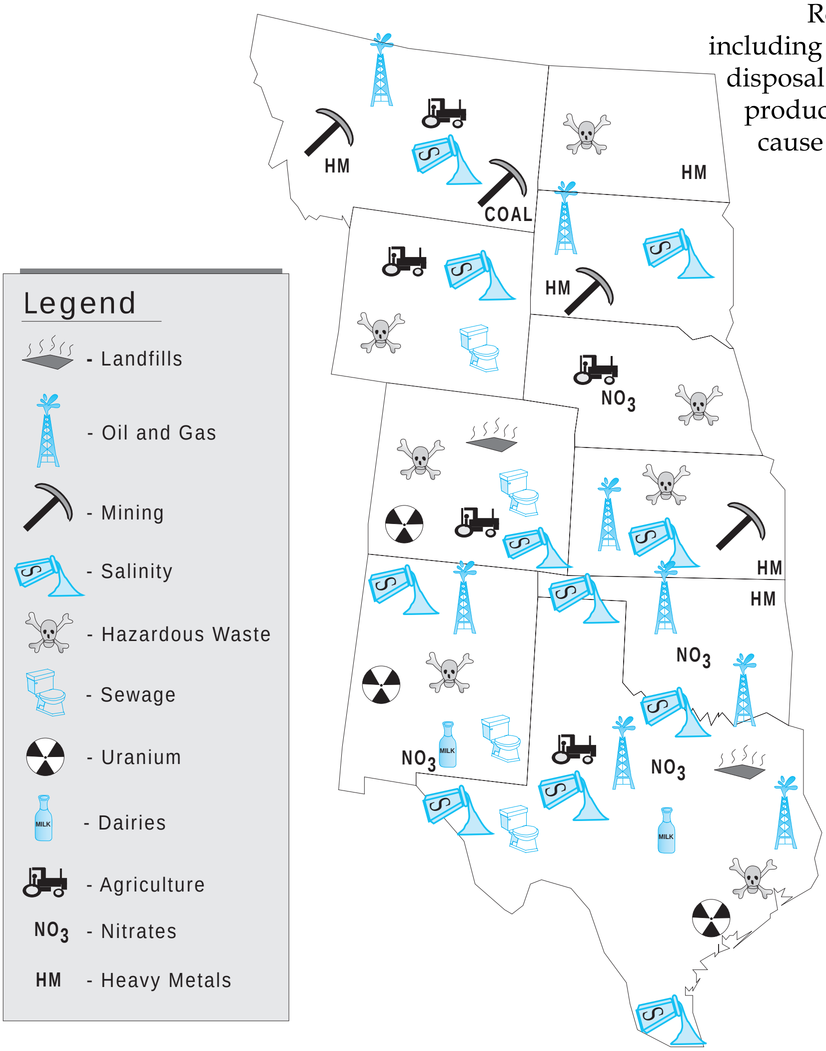
When leaks occur, spills often involve high concentrations of pollutants. EPA estimates that as many as 25% of all underground storage tanks will eventually leak and pollute groundwater supplies.

Materials stored in underground storage tanks also can contaminate groundwater supplies. Underground storage tanks (USTs) are used to house gasoline and petroleum products, hydrocarbons, acids, microorganisms, and other hazardous substances. When leaks occur, spills often involve high concentrations of pollutants. Because USTs are found in both rural and urban regions, the potential for pollution is widespread. EPA estimates that as many as 25% of all underground storage tanks will eventually leak and pollute groundwater supplies. Contamination risks may be reduced through the use of double- lined fiberglass tanks and other materials which are less likely to corrode. Monitoring systems can readily detect when leaks occur providing an opportunity for early clean-up.

Oil, gas, and **solution mining** are potential sources of contamination. **Brines** are salty oilfield wastes with chloride levels of more than 50,000 parts per million that are produced as part of the oil drilling process. Improper brine disposal can make aquifers too saline for use for drinking water and irrigation. Brines are highly corrosive, can damage well casings and increase the potential for contaminants to move into and out of aquifers. Because oil and gas wells often extend deep into geologic formations, they often penetrate through multiple aquifers and provide pathways for contaminants to flow between aquifers.

In some areas, **uranium** and **sulfur** are mined by injecting solutions that leach these substances from rock formations. Related activities including storage and disposal of waste products can also cause contamination.

Selected Groundwater Quality Problems in Great Plains States



Wellhead Protection Programs

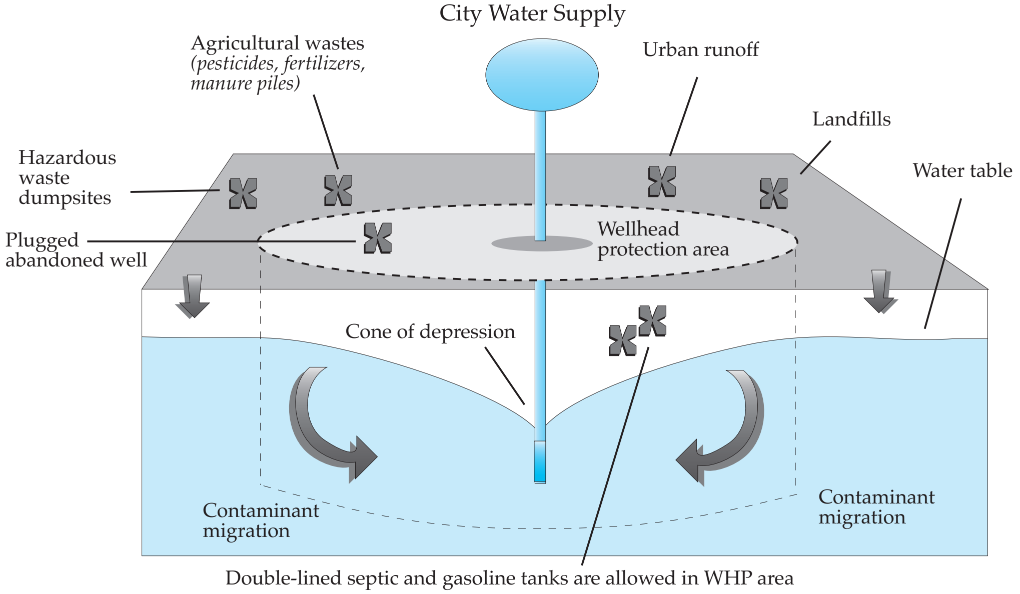
Many cases where agricultural chemicals and pesticides have been found in rural wells result from unsafe handling and use practices around individual wells. A way to reduce the risk of polluting drinking water wells is through **wellhead protection programs**. A National Wellhead Protection Program was established by Amendments to the Safe Drinking Water Act in 1986. This program is directed by EPA.

Communities can use this program to identify and manage areas surrounding drinking water wells and well fields to reduce pollution risks. Wellhead protection measures can range from steps to protect individual wells to major land use planning and zoning ordinances.

EPA has broad guidelines for areas that may want to establish wellhead protection programs. These include: 1) forming community planning teams to specify the roles and duties of state agencies, local governments, and public water suppliers; 2) defining the wellhead protection area around the wells that will be protected; 3) identifying and locating potential sources of contamination; 4) using zoning regulations or other management measures to ban potential contaminant sources within the wellhead protection area; 5) developing contingency plans to respond to contamination events; and 6) incorporating wellhead protection principles in long-range planning to protect future drinking water supply well sites. EPA stresses that getting the public involved is a key to developing successful programs.

EPA also administers the Comprehensive State Groundwater Protection Program. That program involves developing integrated groundwater protection goals that can be shared by federal, state, and local efforts. This could include goal setting, establishing priorities based on aquifer characteristics, defining the roles of individual agencies, and implementing programs, coordinating and collecting information, and improving public education and involvement efforts.

Wellhead Protection Program



Groundwater Quantity

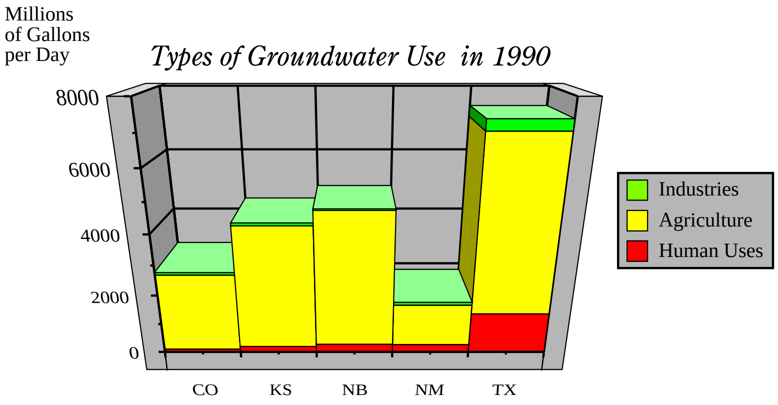
Groundwater is a significant resource throughout much of the Great Plains. For example, groundwater provides more than 85% of the total amount of water used in Kansas, two-thirds in Texas, and more than half in Nebraska and Oklahoma.

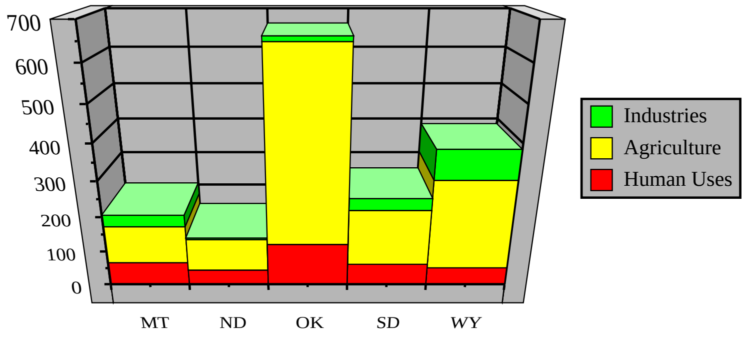
The amount of groundwater pumped by Great Plains states in the region averaged 2,272 millions of gallons per day (gpd) in 1990. Pumping was greatest in Texas (7,390 mgd), Nebraska (4,790 mgd), and Kansas (4,360 mgd). Four states in the region (Wyoming, North Dakota, Montana, and South Dakota) each pumped less than 400 mgd.

The High Plains Aquifer

Much of the water is pumped from the massive High Plains or Ogallala Aquifer, which contains an estimated 3.25 billion acre feet (AF) of water that can be recovered. An AF is the amount of water it would take to cover an acre of land to a depth of one foot or 325,851 gallons.

Just how important is the High Plains Aquifer to the region's water supplies? Looking at a map of the aquifer can yield some clues. For example, the aquifer is a vital and life-giving resource in vast areas in many states. Where it is found, it is critically important. However, it only extends to small portions of many states in the region — the Panhandle in Texas and Oklahoma, eastern Colorado, New Mexico, and Wyoming. The aquifer isn't even found in Montana and North Dakota. Some cities in the region like San Antonio and Denver pump large amounts of groundwater from other aquifers.

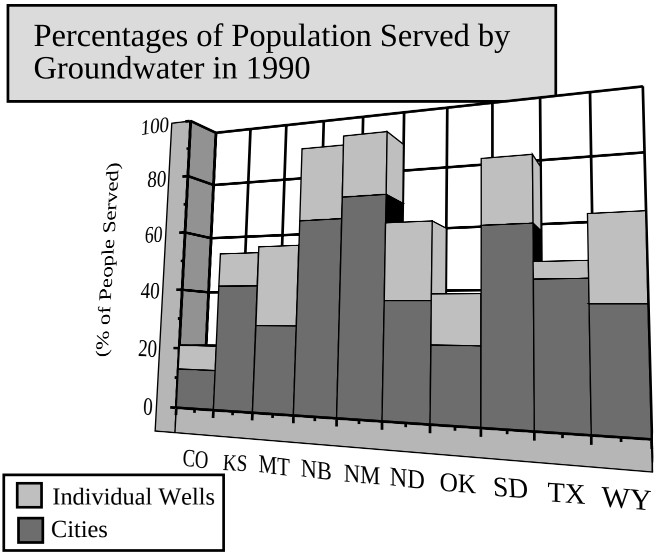




One way of looking at the importance of the aquifer is by comparing the amount of water provided by it as compared to other groundwater supplies. The aquifer supplies as much as 92% of the groundwater in Nebraska, 83% in Kansas, and 74% in South Dakota. In contrast, it only contributes 35% of the total groundwater use in Colorado.

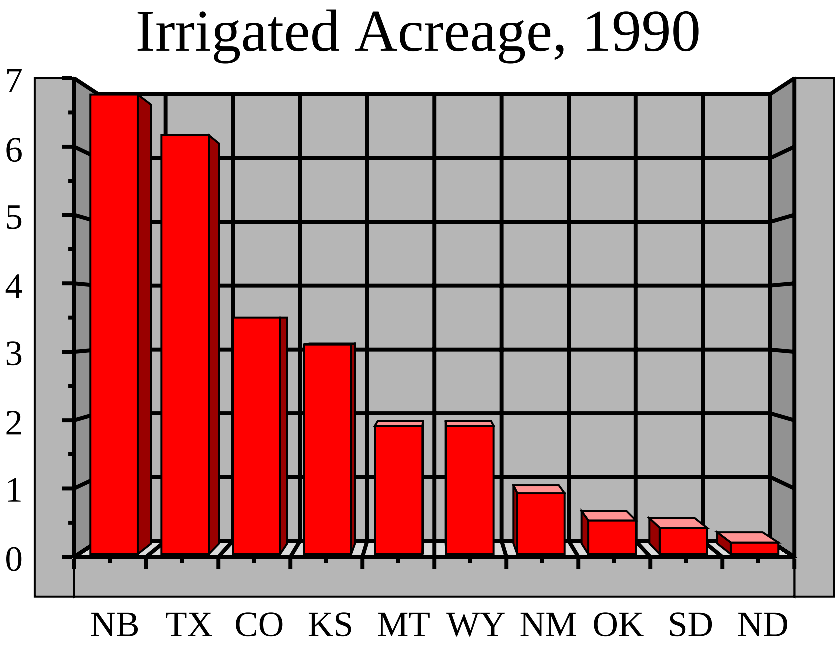
Population Served by Groundwater

How important is groundwater to the people of the Great Plains? Roughly 40% of the region (1.2 million people) depend on groundwater for drinking water supplied by municipal water systems and individual wells. Groundwater serves 90% of the residents of New Mexico, 86% of those in Nebraska, and 78% of South Dakotans. In addition, more than half the people in Kansas, Montana, North Dakota and Wyoming rely on groundwater. Nearly 40% of the region's population was served by municipal groundwater-based systems (New Mexico was highest with 70%). Only 10% of the region's population was served by individual wells, but in Nebraska, Montana, North Dakota and Wyoming that jumped to 25%. Texas pumped the most groundwater for public supplies (1,270 mgd), while Nebraska pumped the most for individual wells (48 mgd).


Percentages of Population Served by Groundwater in 1990

Computing Uses for a Limited Resource

How are groundwater supplies divided among competing uses in the region? More than 85% of the groundwater pumped is used to irrigate 25 million acres of agricultural crops. Groundwater use and irrigated acreage were greatest in Nebraska (4,360 mgd pumped to irrigate 6.8 million acres), Texas (5,600 mgd for 6.1 million acres), and Colorado (2,560 mgd for 3.5 million acres). Livestock and aquaculture accounted for only 2% of the groundwater pumped, with Nebraska (108 mgd), Texas (93 mgd) and Kansas (84 mgd) using the most.


Irrigated Acreage, 1990

Slightly more than 10% of the groundwater that was pumped in 1990 was used for direct human uses (2,255 mgd for municipal supplies and 294 mgd for individual wells). Texas pumped the most groundwater for both categories (1,270 mgd for municipal supplies and 93 mgd for individual wells), followed by Nebraska (235 mgd for municipal supplies and 47 mgd for individual wells) and New Mexico (241 mgd for municipal supplies and 24 mgd for individual wells).

Commercial uses including industries and mining combined to utilize more than 3% of the groundwater pumped in the region. Commercial uses totaled 99 mgd, industries 316 mgd, and mining 322. Commercial uses were greatest in Colorado (7 mgd) and Kansas (6 mgd). Industrial use was highest in Texas (143 mgd) and Nebraska (39 mgd), and groundwater use for mining was greatest in Texas (93 mgd) and Wyoming and New Mexico (both 75 mgd).

Groundwater Declines

In some parts of the Great Plains, it's estimated that water is being pumped from the Ogallala 10 to 40 times as fast as it's being replaced. One indication that aquifer supplies are being depleted is by looking at the depth that is required to reach groundwater supplies. Water levels have fallen by more than 100 feet in the High Plains Aquifer in some areas since pumping began (see Figure 14 and graph below). Along the Texas Gulf Coast, overpumping has caused local geologic formations to collapse and surfaces to subside by as much as 10 feet in some areas. Because these changes cannot be reversed, many homes and buildings in the region are more vulnerable to flooding, because of the lowered elevations. In many areas, aquifer levels have fallen, resulting in increased pumping costs that make groundwater supplies too expensive for irrigation.

It should be noted that groundwater use in the Great Plains region dropped between 1980 and 1990. Increased irrigation efficiency, increased rainfall, lower surface water availability, and federal programs that reduced the amount of cropland being farmed all helped lower groundwater use. In the future, the amount of water pumped in the region and the extent of future water level declines or rises will probably continue to depend on a combination of these factors.

Changes in Well Depth Over Time
Due to Aquifer Depletion

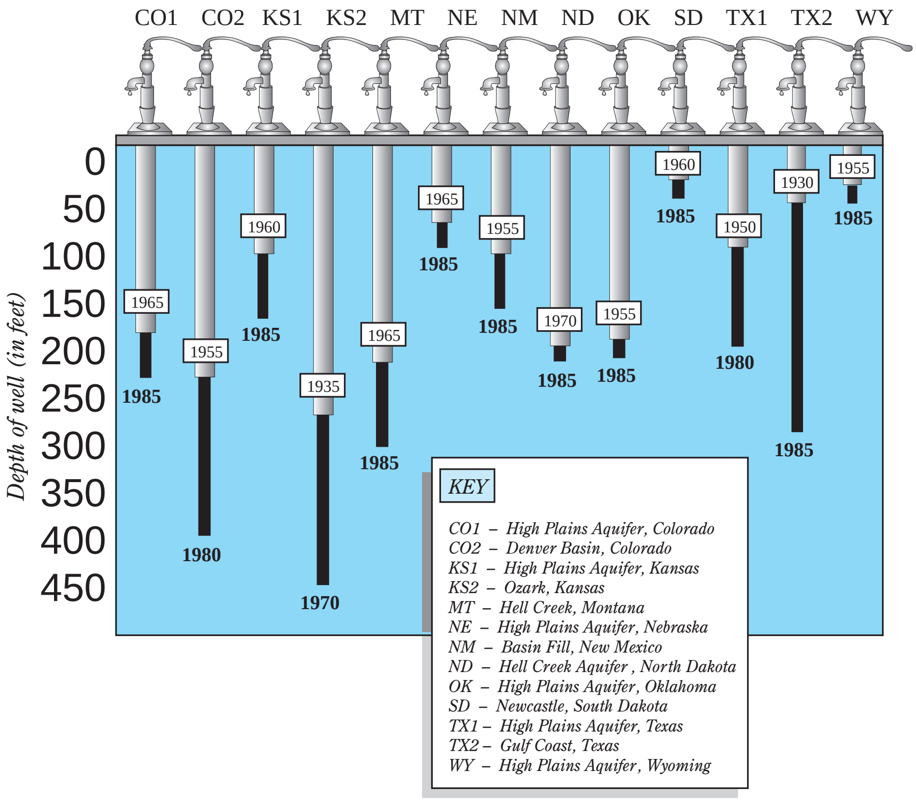
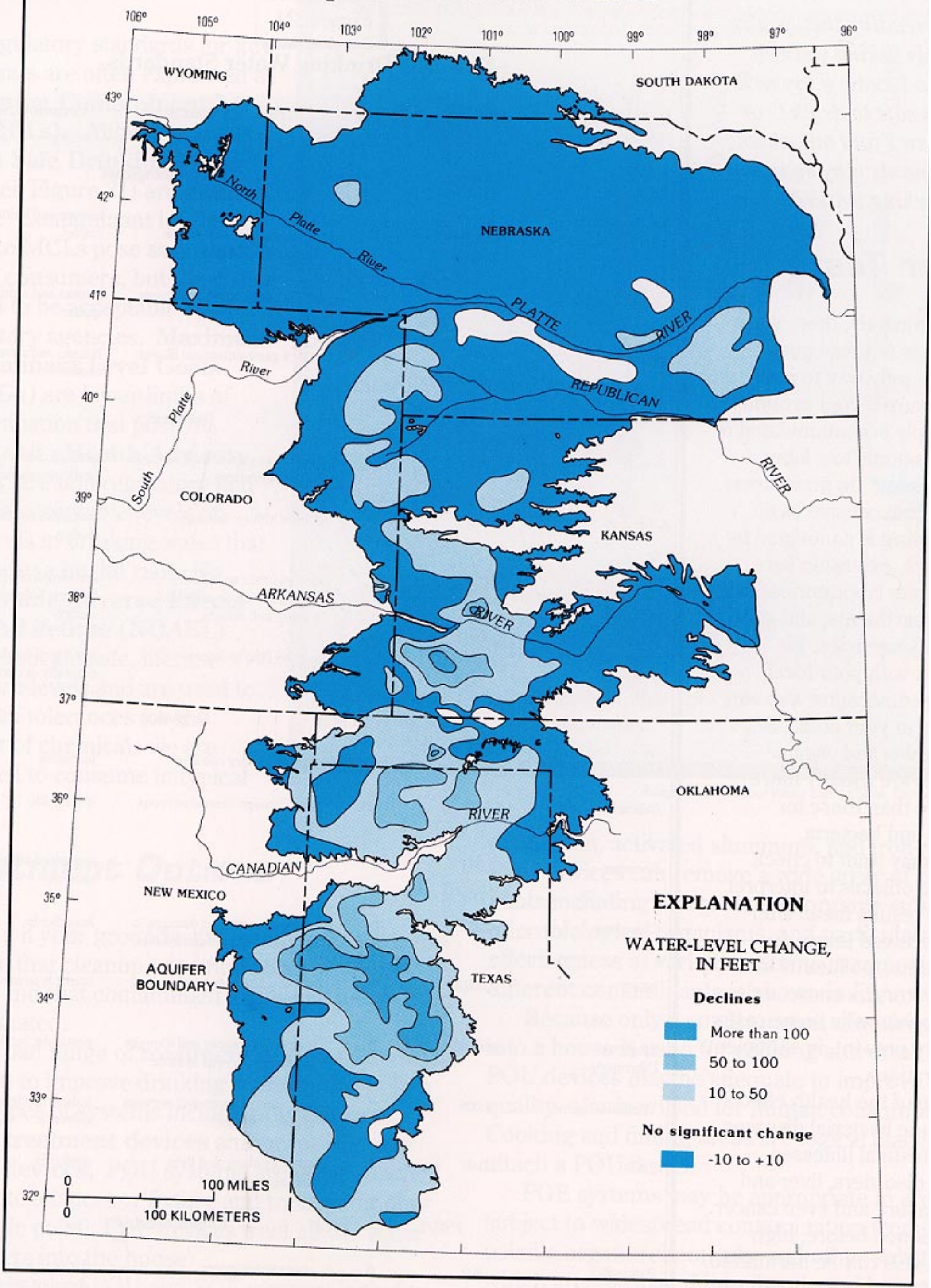


Figure 20

Groundwater Declines in the High Plains Aquifer from 1940 to 1981



Map from Geohydrology of the High Plains Aquifer, *U.S.G.S., 1981*

Contamination and Health Issues

After reading this, you're probably asking yourself "How do I know if my well water is safe to drink?" or "How can I find out which contaminants may be in my drinking water?"

Water Testing

Unfortunately, there's no easy answer to these questions. The only way to really know for sure if your groundwater supply is contaminated is to send a sample to a laboratory for testing. In many areas, relatively inexpensive **water testing** is conducted by universities, extension services, private laboratories, local health departments, and state and county agencies.

Check with your local officials to determine who can test water in your area. Tests for pesticides and organic chemicals are usually more expensive than those for minerals and bacteria.

You may want to check with local officials to interpret what the results mean after you've received them. In simple terms, pollutants in groundwater *can* cause serious health problems in some cases *if* they are present in sufficient concentrations.

Some of the health effects can include bacterial diseases, gastrointestinal illnesses, nervous disorders, liver and kidney failure and even cancer. As mentioned before, high nitrate levels *can* be harmful to infants.

Figure 21
Selected Drinking Water Standards

Contaminant	MCL	MCL Goal*	Health Impacts	Common Sources
	ppm	**ppm**	**Microbiologicals**	
Total Coliforms	less than 5% positive per month	0	indicates the presence of organisms that may cause gastrointestinal illness	human and animal fecal matter
Giardia Lambia	0**	0	causes gastrointestinal illness	human and anima fecal matter
Viruses	0**	0	causes gastrointestinal illness	human and anima fecal matter
	ppm	**ppm**	**Inorganics**	
Arsenic	0.03	0	may cause cancer and nervous system disorders	geologic sources; pesticide residue
Cadmium	0.005	0	causes kidney damage	industrial wastewater and sludge
Lead	0.015*	0	causes brain and kidney damage; toxic to pregnant women and infants	leaching from pipes and solders; wastewater and sludge
Nitrate-Nitrogen	10	10	may be fatal to infants	fertilizers, feedlots, naturally occurring
	ppm	**ppm**	**Organics**	
Alachlor	0.002	0	may be cancer causing	herbicide
Aldicarb	0.03	0.0001	may damage central nervous system	insecticide
Benzene	0.005	0	cancer causing	industrial effluents and solvents
Chlordane	0.002	0	may cause cancer, damage to liver, central nervous system	insecticide
DBCP	0.0002	0	may cause cancer and reduce fertility	controls nematodes
Ethylene Dibromide	0.00005	0	may cause cancer and damage to central nervous system	pesticide, fumigant
Trichlorethylene	0.005	0	may cause cancer and nervous system damage	industrial cleaning solvents
2,4-D	0.07	0	causes kidney and liver damage	pesticide
	PiC/L	**PiC/L**	**Radionuclides**	
Radon-222	300	0	may cause cancer	decay of naturally occurring radium

Regulatory Standards

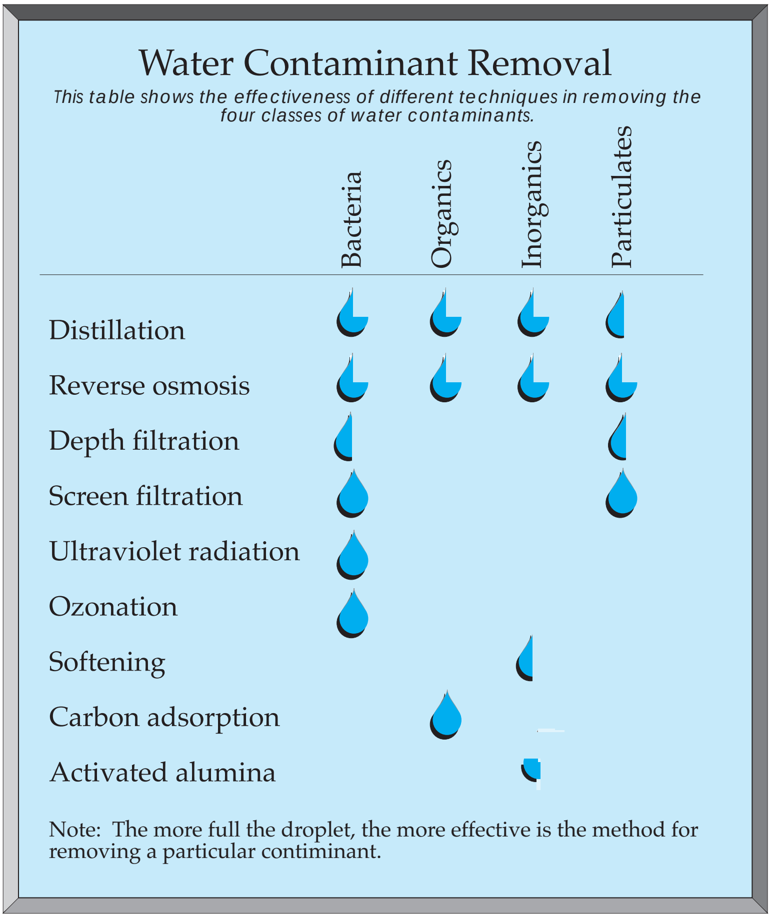
Regulatory standards for key pollutants are often expressed as **Maximum Contaminant Levels (MCLs).** Allowable levels for the **Safe Drinking Water Act** are given as MCLs. Contaminant levels equal to MCLs pose some health risk to consumers, but the risk is judged to be acceptable by regulatory agencies. **Maximum Contaminant Level Goals (MCLGs)** are lower limits of contamination that pose no health risk. **Health Advisory Levels** are non-regulatory and indicate acceptable levels of chemicals in drinking water that don't pose a health risk. **No Observable Adverse Effects over a Lifetime (NOAEL)** values indicate safe, lifetime exposure levels and are used to establish tolerances for the amount of chemicals we are expected to consume in typical diets.

Treatment Options

Even if your groundwater is contaminated, it is possible that cleanup or remediation can be successful and that contaminant levels can be reduced or eliminated.

A broad range of **treatment options** have the potential to improve drinking water quality. Two broad types of systems include point-of-use **(POU) treatment devices** and **point-of-entry (POE) devices**. POU systems are often attached directly to a faucet or fixture and treat water only at a single point. POE devices treat all the water that enters into the house.

Examples of POU and POE systems include the use of screens and filters, activated carbon, ultraviolet light, ozone, reverse osmosis, softening, distillation, activated aluminum, and iron removal. POU devices can remove a wide array of contaminants, including inorganic and organic substances, microbiological organisms, and particulates.



Water Contaminant Removal

This table shows the effectiveness of different techniques in removing the four classes of water contaminants.

	Bacteria	Organics	Inorganics	Particulates
Distillation	💧	💧	💧	💧
Reverse osmosis	💧	💧	💧	💧
Depth filtration	💧			💧
Screen filtration	💧			💧
Ultraviolet radiation	💧			
Ozonation	💧			
Softening			💧	
Carbon adsorption		💧	💧	
Activated alumina			💧	

Note: The more full the droplet, the more effective is the method for removing a particular continimant.

Adapted from Is your Water Safe to Drink, *Consumers Union*

Because only a small amount of water coming into a house is used for cooking and drinking, POU devices may be adequate to improve the quality of water used for human consumption. Cooking and dining areas are logical places to attach a POU device.

POE systems may be appropriate in areas subject to widespread contamination from radon, volatile organic chemicals, and other substances which are dissipated into the air and become hazards in homes and other enclosed spaces.

Public Involvement - What Can I Do?

Involvement by interested public citizens is perhaps the biggest resource we have to prevent groundwater from becoming contaminated and to protect groundwater supplies.

Avoid Polluting Practices

Become aware of the issues involved and learn how to **avoid polluting practices**. This includes learning how to safely use and dispose of household and agricultural chemicals. Never pour any of these substances on the ground (especially near wells, streams and rivers), always follow label directions, dispose of chemicals and empty chemical containers safely in designated facilities, and consider buying non-toxic alternatives. Your community may also have special events to collect and dispose of hazardous chemicals. Take part in these activities. If your area doesn't yet have this type of program, you might want to contact local officials to begin this type of effort.

Use Chemicals Safely

When using agricultural chemicals, always follow labeled recommendations and make sure you apply the proper amount. Avoid applying agricultural chemicals when heavy rain is forecast. Extension specialists and Soil Conservation Service personnel can provide additional information on safe chemical management practices in your area. Some areas are especially vulnerable to contamination. Find out if you live in such an area and take special precautions to protect water quality.

Maintaining active water wells, plugging abandoned wells, proper care and operation of septic tanks and drainfields, and replacing leaking storage tanks can also help ensure maintenance of groundwater quality.

There are also a number of other ways individuals can get involved in groundwater protection efforts. States are developing **wellhead protection programs** which encourage citizen participation to protect public water supplies. In these programs, residents help inventory sites of existing and abandoned wells and develop background information on likely sources of contamination. In some areas, voluntary **groundwater monitoring programs** have been established. Citizens regularly inspect wellhead and recharge areas to look for observable signs of contamination.

Work with Water Districts

Many areas also have **groundwater protection, conservation, and management districts** which often carry out activities that encourage public education and involvement. These districts encourage conservation and manage groundwater systems on a local level.

Conserve!

There are many things individuals can do to conserve water. For example, new technologies and management strategies can dramatically reduce residential, agricultural, and industrial water use. Simple steps such as taking shorter showers, purchasing appliances like dishwashers and washing machines that use less water, and only washing cars and irrigating lawns when needed can all save water. Some states have passed laws requiring the sale of water-conserving toilets and other devices. Water efficient landscapes that utilize low water-using plants and grasses, and management strategies can save water in urban areas.

Industrial water use can be reduced through recycling and adoption of new technologies. Where regulations allow, groundwater pumping can be reduced by reusing wastewater effluents for irrigation or in industry.

Summary

Groundwater is a vital resource for many parts of the United States. The importance of groundwater is especially felt in semi-arid areas like the Great Plains that depend so much on the High Plains Aquifer and other groundwater systems. In general, rural areas are especially reliant upon abundant supplies of clean groundwater.

Proper management of groundwater quantity is needed to protect water supplies. Otherwise, mining or overpumping could low water tables, boost pumping costs, degrade water quality and increase the likelihood of subsidence. Conservation and efficient use need to be emphasized, particularly in agriculture which accounts for a large percentage of groundwater use.

Groundwater is also threatened by a number of so-called "natural" contaminants – elements in the environment that may impair water quality. It may be difficult or impossible to reclaim water that has been contaminated by natural conditions because of the widespread nature of the contamination. However, there are a number of contaminants that we can do something about. Man-made contamination can be reduced.

Pollution prevention may be as easy and cost-effective to carry out as polluting activities. It actually costs agricultural producers more to apply excessive amounts of nitrogen fertilizers (after a given point the crops don't benefit from the additional nitrogen) than it does to apply only as much nitrogen as crops need. The value of recycled goods (printed products, aluminum cans, and glass) now more than pay for the processes used to reclaim them.

It seems obvious that if we allow groundwater systems to become polluted we are running a definite environmental, economical, and social risk. Because so many areas depend solely on groundwater, aquifer pollution may leave those regions essentially without water and certainly without inexpensive, high quality water. Because groundwater can be so difficult and expensive to clean up, groundwater pollution adds an economic burden on taxpayers who must pay for restoration and interim water supplies until cleanup efforts are complete.

Certainly, groundwater is a resource whose quality and quantity are worth protecting.

Groundwater Vocabulary

Aquifer – A water-bearing layer of rock, sand, or gravel that is capable of yielding a usable supply of water.

Aquifer Depletion (Mining) – Withdrawing groundwater over prolonged periods at rates that exceed the average rate of recharge.

Artesian Aquifer – A confined aquifer in which the pressure at the water surface is greater than the atmospheric pressure. In some artesian aquifers, pressurized water flows to the surface without having to be pumped.

Background Water Quality — the pre-existing conditions of a particular groundwater system that has not been altered by human activities. Almost all groundwater contains some levels of natural contaminants including sodium, chloride, and many others. Virtually no aquifer contains pure groundwater. In some cases, this natural contamination may be severe enough to limit the use of the aquifer. In areas relatively free of man's activity, background water quality provides a benchmark that can be used to compare the original water quality to present conditions.

Brine — Highly salty, mineralized water containing heavy metals and organic contaminants. Brine often accompanies oil and gas deposits which exist below drinkable groundwater supplies.

Contaminant – Physical, chemical, biological, or radiological constituents that degrade water quality or lessen its purity. Many waters are contaminated by naturally or man-made substances.

Discharge – The flow of groundwater into artesian wells, streams or springs, or withdrawal by pumpage.

Drainage Wells – Wells used to carry excess water off agricultural fields. Because they act as a funnel from surface to ground waters, drainage wells can result in groundwater contamination.

Groundwater – Water which saturates soils and cracks, caverns, sand, gravel and other porous subsurface rock formations. Groundwater occurs in the saturated zone.

Hardness – A water condition typically caused by dissolved calcium, sulfates, magnesium and iron combined with bicarbonates and carbonates. Hard water can produce scales in hot water lines and appliances and lessen the cleaning power of soaps.

Health Advisory Level – Health-based warning levels for chemicals in drinking water. Below this level, health risks are acceptable when these chemicals are ingested over given periods of time.

Hydrologic Cycle – The ongoing process by which nature redistributes water throughout the earth. Components of the hydrologic cycle include precipitation, evaporation, transpiration, and recharge of groundwater systems, rivers, lakes, and oceans.

Impairment – Water quality degradation that makes water unfit for a specific use. For example, water may be so salty that it's impaired for use as drinking water. However, it could still be used to irrigate salt-tolerant crops or for certain industrial purposes.

Karst – Geologic formations comprised of fractured and fissured limestone rocks and sinkholes. Karst aquifers present special pollution problems because contaminants can be easily introduced at the surface.

Leaching – The downward movement of dissolved or suspended minerals, agricultural chemicals and other substances through soils into groundwater systems.

Maximum Contaminant Levels (MCLs) – The maximum level of a contaminant allowed by federal law. MCLs are based on health effects and available treatment methods.

Groundwater Vocabulary

Nitrate – Nitrate is an important plant nutrient and inorganic fertilizer, and may be formed by the breakdown of plant and animal residues and wastes. Major sources of nitrate pollution in groundwater include septic tanks and drainfields, manure from feedlots and dairies, agricultural fertilizers, wastewater effluents, and sanitary landfills.

Non-Point Sources of Contamination – Contaminants that originate from undefined or non-specific sources including runoff from construction sites, mining, forestry, streets, and agricultural fields.

No Observable Adverse Effects over a Lifetime (NOAEL) – NOAEL values indicate safe, lifetime, exposure levels to chemicals. They are used to establish tolerances for human ingestion of chemicals in the diet.

Perched Water Tables – Isolated pockets of water separated from the main portion of the aquifer by clay or other materials water cannot easily penetrate through. Perched water tables are often temporary and usually do not yield large amounts of water over a long period of time.

Permeability – The capacity of porous rocks and geologic formations to transmit water.

pH – A numerical measure of acidity used to distinguish alkaline, neutral, and acidic waters. The pH scale ranges from 1 to 14. A pH of 7 is neutral, values below 7 are acidic, and values above 7 are alkaline.

Point Sources of Contamination – Contamination from specific sources such as leaking underground storage tanks, introduction of chemicals into a well, or wastewater discharges from a pipe.

Pollution – Water quality degradation in excess of established regulatory guidelines. For example, water with substances in excess of levels allowed by the Safe Drinking Water Act, the Clean Water Act, or other regulations is polluted. Pollution may also make water of too poor quality for specified uses such as drinking water.

Porosity – The relative volume of pores or cavities in a soil, sand, rock or gravel formation. Porosity usually refers to the amount of water and air that can be stored within different geologic formations.

Recharge Zones – Areas on the surface where water is likely to flow into groundwater systems in relatively large volumes. Examples of recharge zones include streams that travel over areas with fractured and fissured soils and lose part of their flows and areas that provide snowmelt. Strategies to increase recharge can include the use of recharge basins, limitations on paved areas, and dams that intercept rainfall runoff and convey it to groundwater systems.

Saturated Zone – A portion of a geologic formation where all the pores are filled with water. There may be multiple saturated zones within a single aquifer separated by clay and rock layers.

Residence Times — The length of time water is in a groundwater system. Residence time begins when water infiltrates into an aquifer and ends when the water is discharged by springs, river flows, or pumpage. Flow rates influence the residence time.

Sole Source Aquifer – An aquifer specifically designated by the Safe Drinking Water Act that is of critical value or is the only major supply of drinking water for a specific area.

Subsidence — Compaction of aquifers and lowered surface elevations caused by overpumping.

Unsaturated Zone – That portion of the soil profile which contains both air and water. Also known as the vadose zone.

Water Table – The top boundary of the saturated zone.

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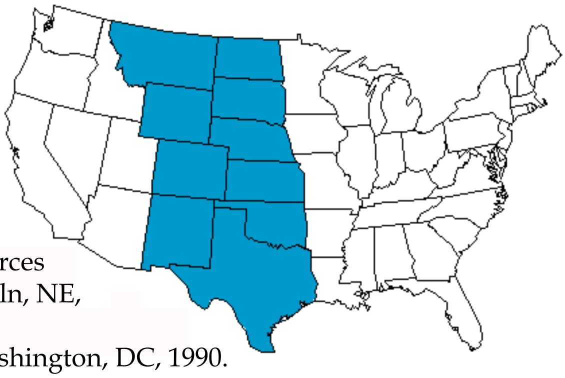

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For More Information

Colorado Cooperative Extension Service , 271 Ellsworth Hall, Colorado State University Fort Collins, CO 80523. Phone: (970) 491-6281. WWW: http://www.colostate.edu/Depts/CoopExt/

Colorado Water Resources Research Institute, 601 Howes St., #410 - Fort Collins, CO 80523 - Phone: (970) 491-6308. E-Mail: cwrri@colostate.edu. WWW: http://yuma.acns.colostate.edu/Depts/CWRRI/

Kansas Cooperative Extension Service, 113 Waters Hall, Kansas State University, Manhattan, KS 66506. Phone: (913) 532-7137. E-Mail: agdean@ksu.edu. WWW: http://www.oznet.ksu.edu

Kansas Water Resources Research Institute, Kansas State University, 144 Waters Hall, Manhattan, KS 66506-4007. Phone: (913) 532-5729.

Montana Cooperative Extension Service, 204 Culbertson Hall, Montana State University, Bozeman, MT 59717. Phone: (406) 994-6647. WWW: http://www.montana.edu/wwwcx/

Montana University System Water Center, 101 Huffman Building, Montana State University, Bozeman, MT 59717. Phone: (406) 994-6690. E-Mail: wwwrc@gemini.oscs.montana.edu. WWW: http://www.montana.edu/wwwrc

Nebraska Cooperative Extension Service, 211 Agricultural Hall, Lincoln, NE 68583. Phone: (402) 472-2966. WWW: http://ianrwww.unl.edu/ianr/coopext/coopext.htm

Nebraska Water Resources Center, 103 Natural Resources Hall, University of Nebraska, Lincoln, NE 68583. Phone: (402) 472-3305. WWW: http://ianrwww.unl.edu/ianr/waterctr/wchome.html

New Mexico Cooperative Extension Service, Box 3003, MS 3AE, New Mexico State University, Las Cruces, NM 88003. Phone: (505) 646-3015. WWW: http://www.cahe.nmsu.edu/cahe/ces/

New Mexico Water Resources Research Institute, P.O. Box 30001, MSC 3167, New Mexico State University, Las Cruces, NM 88003. Phone: (505) 646-6418. WWW: http://www.nmsu.edu

North Dakota State University Extension Service, 315 Morrill Hall, North Dakota State University, P.O. Box 5437, Fargo, ND 58105. Phone: (701) 231-8944. WWW: http://www.ext.nodak.edu/

North Dakota Water Resources Research Institute, Chemistry Department, North Dakota State University, Fargo, ND 58105. Phone: (701) 231-7193.

Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, OK, 74078. WWW: http://www.okstate.edu/OSU_Ag/oces/.

Oklahoma State University Environmental Institute, 003 Life Sciences East, Oklahoma State University, Stillwater, OK 74078. Phone: (405) 744-9994. WWW: http://seic.lse.okstate.edu/envinst/.

South Dakota Cooperative Extension Service, Agricultural Hall 154, Box 2207-D, South Dakota State University, Brookings, SD 57007. Phone: (605) 688-4792. WWW: http://www.abs.sdstate.edu/CES/.

South Dakota Water Resources Institute, South Dakota State University, Box 2120, Brookings, SD 57007. Phone: (605) 688-4910. WWW: http://www.abs.sdstate.edu/Wrri/index.htm

Texas Agricultural Extension Service, Texas A&M University, College Station, TX 77843. Phone: (409) 845-7967. E-Mail: agextension@tamu.edu. WWW: http://agcomwww.tamu.edu/agcom/taex/taex.htm.

Texas Water Resources Institute, 301 Scoates Hall, Texas A&M University, College Station, TX 77843, Phone: (409) 845-1851. E-Mail: twri@tamu.edu. WWW: http://twri.tamu.edu

Wyoming Cooperative Extension Service, University of Wyoming, Laramie, WY 82071. Phone: (307) 766-5124. WWW: http://www.uwyo.edu/ag/ces/ceshome.htm.

Wyoming Water Research Center, P.O. Box 3067 University Station, University