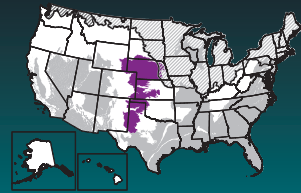


# Groundwater Quality in the High Plains Aquifer

Groundwater provides nearly 50 percent of the Nation's drinking water. To help protect this vital resource, the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Project assesses groundwater quality in aquifers that are important sources of drinking water. The High Plains aquifer constitutes one of the important aquifers being evaluated.

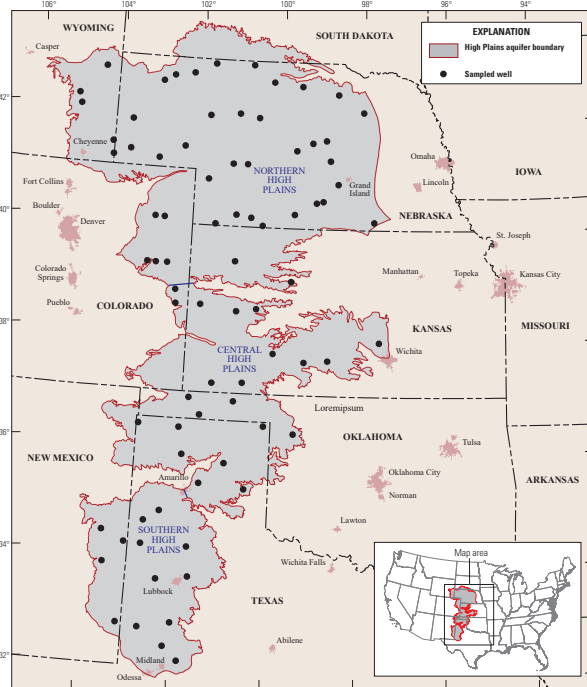


## Background

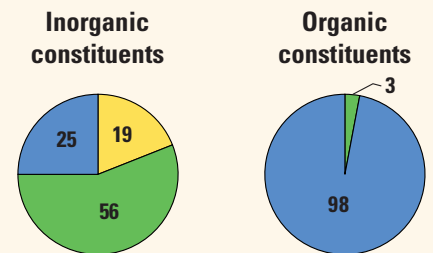
The High Plains aquifer underlies an area of about 169,000 square miles, which is populated by about 2 million people in parts of eight western states (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, Texas, South Dakota, and Wyoming). The aquifer ranks 13th in the Nation as a source of groundwater for public supply, with about 390 million gallons per day pumped for this use in 2000 (Maupin and Barber, 2005; Arnold and others, 2020a). The aquifer is also extensively used for agriculture, ranking first in the Nation as a source of groundwater for irrigation, with water pumped for irrigation markedly higher than for public supply (17,000 million gallons per day). Land use overlying the High Plains aquifer is composed primarily of natural land cover (including rangeland; 59 percent) and agricultural land (37 percent) with relatively small areas of urban and other developed land (4 percent; Homer and others, 2015). About 20 percent of the Nation's irrigated agricultural land overlies the High Plains aquifer. The four largest cities that lie within the aquifer's overlying land are Amarillo, Lubbock, and Midland, Texas, and Cheyenne, Wyoming. Most of the population of the region reside in smaller cities and towns and rural areas. Urban development is much less widespread than agriculture over the High Plains aquifer.

The extensive area of the High Plains aquifer includes a wide range of topography and climate and as a result is commonly divided into three geographic subregions: the Northern, Central, and Southern High Plains (McMahon and others, 2007). Precipitation generally decreases from east to west, and temperatures increase from north to south (Thornton and others, 1997). The aquifer is described in detail by McMahon and others (2007) and summarized here. The High Plains aquifer is generally unconfined and is composed of Tertiary and Quaternary near-surface deposits that form six hydraulically connected hydrogeologic units. The Ogallala Formation, which has the largest areal extent of these units, consists primarily of unconsolidated clay, silt, sand, and gravel with locally cemented carbonate zones. Older sedimentary bedrock units underlie the aquifer. Evaporation rates are some of the highest in the Nation, owing to high summer air temperatures and persistent winds. Because evaporation rates exceed precipitation across much of the study area, little water recharges the aquifer. Recharge that does occur is primarily by infiltration of irrigation water; diffuse infiltration from precipitation; focused infiltration of storm and irrigation water runoff through streambeds, playas, and other topographic depressions; and upward movement of water from underlying aquifers. Discharge occurs primarily by irrigation-well pumping, discharge to streams and underlying aquifers, flow across the eastern boundary of the aquifer, and evapotranspiration. Regional groundwater flow is generally from west to east. Substantial water-level changes have occurred in the High Plains aquifer. Because groundwater withdrawals have greatly exceeded recharge rates across much of the aquifer, water-level declines are common across parts of Kansas, Oklahoma, New Mexico, and Texas.

Groundwater quality in the High Plains aquifer was evaluated in 2015 and 2016 by sampling 80 public-supply wells that were spatially distributed across the aquifer. For this discussion, we define the study area as the depth zone used for public supply in the High Plains aquifer. Water-quality data collected from the spatially distributed wells (7 in Colorado, 11 in Kansas, 32 in Nebraska, 4 in New Mexico, 4 in Oklahoma, and 5 in Wyoming were sampled in 2015; 17 were sampled in Texas in 2016) are representative of water quality in the study area, following the approach described by Belitz and others (2010). This approach allows for the estimation of the percentage of the study area with concentrations that are high, moderate, and low with respect to constituent benchmarks. The accuracy of the estimates depends on the distribution and number of wells, not the size of the area (Belitz and others, 2010). The wells ranged from 54 to 812 feet deep (averaging 282 feet deep) and were typically open to the aquifer across a range of depth intervals ranging from 10 to 375 feet (averaging about 84 feet). Samples were analyzed for a large number of water-quality constituents derived from natural and human sources.



## Overview of Water Quality



### CONSTITUENT CONCENTRATIONS

● High ● Moderate ● Low or not detected

Values are a percentage of the study area with concentrations in the three specified categories. Percentages might not sum to 100 because of rounding.

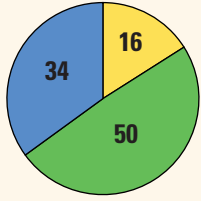
Principal Aquifer Studies (Buwor and Belitz, 2014) are designed to evaluate groundwater used for public supply prior to any treatment. Groundwater quality is assessed by comparing concentrations to benchmarks established for drinking-water quality. Benchmarks and definitions of high, moderate, and low relative concentrations are discussed at the bottom of page 3. Water from 81 percent of the wells sampled did not have high concentrations relative to benchmarks of any constituent measured.

Many inorganic constituents are naturally present in groundwater. The concentrations of inorganic constituents can be affected by natural processes as well as by human activities. One or more inorganic constituents with human-health benchmarks were detected at high concentrations in about 19 percent of the study area and at moderate concentrations in about 56 percent.

Organic constituents derived from human activities are used in household, business, industrial, and agricultural products. They can enter the environment through normal usage, spills, or improper disposal. Organic constituents with human-health benchmarks were detected at moderate concentrations in 3 percent of the study area.

# Results: Groundwater Quality at the Depth Zone Used for Public Supply in the High Plains Aquifer

## INORGANIC CONSTITUENTS



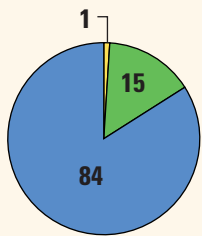
**Trace elements and major and minor ions**

### Inorganic Constituents With Human-Health Benchmarks

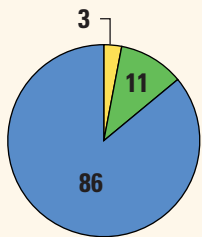
Trace elements and major and minor ions are naturally present in the minerals of rocks, soils and sediments, and in the water that comes into contact with those materials. Samples were analyzed for 34 trace elements and major and minor ions, of which 22 have human-health benchmarks (health-based screening level [HBSL] benchmarks were updated in 2018 to include aluminum, cobalt, and iron). Constituents from this group were detected at high concentrations in about 16 percent of the study area (the depth zone used for public supply) and at moderate concentrations in about 50 percent. Uranium and arsenic were the trace elements most frequently detected at high concentrations (8 and 6 percent, respectively). Uranium, arsenic, and fluoride were detected at moderate concentrations in about 15, 44, and 13 percent of the study areas, respectively. Strontium was detected at high or moderate concentrations in about 11 percent of the study area.

Radioactivity is the release of energy or energetic particles during the spontaneous decay of unstable atoms. Humans are continuously exposed to small amounts of natural radioactivity. Most of the radioactivity in groundwater comes from the decay chain of isotopes of uranium and thorium that are naturally present in minerals in aquifer materials. Samples were analyzed for eight radioactive constituents, of which four have human-health benchmarks. Radioactive constituents, primarily resulting from gross-alpha activity, were present at high levels in about 1 percent of the study area and at moderate levels in about 15 percent of the study area.

Nutrients are naturally present at low concentrations in groundwater; high and moderate concentrations (relative to human-health benchmarks) generally result from human activities. Samples were analyzed for five nutrients, of which two (nitrate and nitrite) have human-health benchmarks. Common sources of nutrients, aside from soils, include fertilizer applied to crops and landscaping, seepage from septic systems, and human and animal waste. Nitrate was measured at high concentrations in about 3 percent of the study area and at moderate concentrations in about 11 percent. Previous studies have noted that nitrate concentrations in the High Plains aquifer are higher in shallow groundwater relative to deeper and older groundwater (Bruce and Oelsner, 2001; McMahon, 2001; Gurdak and others, 2009).



**Radioactive constituents**



**Nutrients**

### Inorganic Constituents and Field Measurements With Non-Health Benchmarks

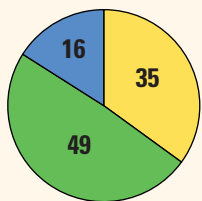
*(Not included in water-quality overview charts shown on the front page)*

Some constituents affect the aesthetic properties of water, such as taste, color, and odor, or can create nuisance problems, such as staining and scaling. The benchmarks used for these constituents were non-regulatory secondary maximum contaminant level (SMCL) benchmarks established for public drinking water. Some constituents, such as manganese and fluoride, have human-health benchmarks and SMCLs. Samples were analyzed for 11 constituents that have SMCLs. One or more of these were present at high concentrations relative to the SMCL in about 35 percent of the study area and at moderate concentrations in about 49 percent.

Total dissolved solids (TDS) concentration is a measure of the salinity of the groundwater based primarily on concentrations of ions. All water naturally contains TDS because of the weathering and dissolution of minerals in rocks and sediments. Concentrations of TDS can be high as a result of natural factors or human activities, such as applications to the land surface of road salt, fertilizers, or other chemicals in urban or agricultural areas. Most of the study area had high (26 percent) or moderate (54 percent) concentrations of TDS. Fluoride and sulfate were present at high concentrations in about 15 and 10 percent of the study area, respectively, and at moderate concentrations in 18 and 11 percent, respectively.

Anoxic conditions in groundwater (low amounts of dissolved oxygen) can result in the release of iron and manganese in minerals to the groundwater. Manganese and iron were measured at high concentrations relative to the SMCL in about 11 and 1 percent, respectively, of the study area.

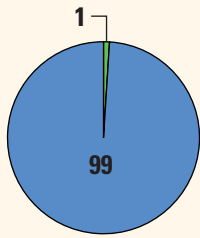
Groundwater pH has an SMCL range of 6.5 to 8.5. In the High Plains aquifer, pH was greater than 8.5, which is alkaline, in about 1 percent of the study area.



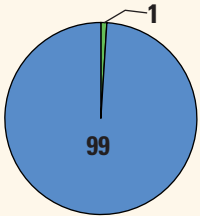
**Constituents with non-health benchmarks**

# Results: Groundwater Quality at the Depth Zone Used for Public Supply in the High Plains Aquifer

## ORGANIC CONSTITUENTS



VOCs



Pesticides

### Volatile Organic Compounds With Human-Health Benchmarks

Volatile organic compounds (VOCs) are present in many household, commercial, industrial, and agricultural products and are characterized by their tendency to volatilize (evaporate). Samples were analyzed for 85 VOCs, of which 51 have human-health benchmarks. VOCs were detected at moderate concentrations in 1 percent of the study area (based on trichloroethylene—TCE—concentration).

### Pesticides With Human-Health Benchmarks

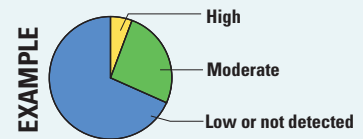
Pesticides, including herbicides, insecticides, and fungicides, are applied to crops, gardens and lawns, around buildings, and along roads to help control unwanted vegetation (weeds), insects, fungi, and other pests. Samples were analyzed for 225 pesticide compounds (pesticides and their breakdown products), of which 119 have human-health benchmarks. Pesticide compounds were detected at moderate concentrations in 1 percent of the study area (based on detections of the herbicide atrazine).

## BENCHMARKS FOR EVALUATING GROUNDWATER QUALITY

The USGS NAWQA Project uses benchmarks established for drinking water to provide context for evaluating the quality of untreated groundwater. The quality of water received by consumers can be different from results presented herein because after withdrawal, groundwater may be treated prior to delivery. Federal regulatory benchmarks for protecting human health are used for this evaluation of water quality when available. Otherwise, non-regulatory human-health benchmarks and non-regulatory aesthetic benchmarks are used. Not all constituents analyzed have benchmarks and, thus, are not considered in this context. Human-health benchmarks are available for 28 of 55 inorganic constituents and properties and 170 of 310 organic constituents.

Concentrations are considered high if they are greater than a human-health benchmark (Norman and others, 2018) or SMCL. For inorganic constituents, concentrations are moderate if they are greater than one-half of a benchmark. For organic constituents, concentrations are moderate if they are greater than one-tenth of a benchmark; this lower threshold is used because organic constituents are generally less prevalent and have smaller concentrations relative to benchmarks than inorganic constituents (Toccalino and others, 2004).

### PERCENTAGE OF STUDY AREA



EXAMPLE Values are a percentage of the study area with concentrations in the three specified categories. Percentages might not sum to 100 because of rounding.

### Benchmark Type and Value for Selected Constituents

This table presents benchmarks for those constituents detected at high concentrations in the High Plains aquifer. Benchmark types are regulatory U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs), non-regulatory health-based screening levels (HBSLs), and non-regulatory EPA secondary maximum contaminant levels (SMCLs).

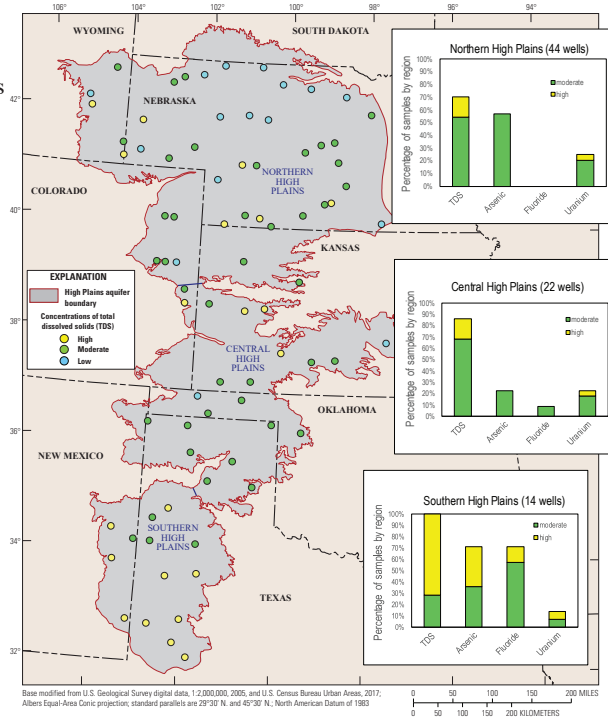
[ppb, part per billion or microgram per liter (µg/L); ppm, part per million or milligram per liter (mg/L); pCi/L, picocurie per liter]

Constituent	Benchmark		Constituent	Benchmark	
	Type	Value		Type	Value
Arsenic	MCL	10 ppb	Total dissolved solids (TDS)	SMCL	500 ppm
Fluoride	MCL	4 ppm	Fluoride	SMCL	2 ppm
Strontium	HBSL	4,000 ppb	Sulfate	SMCL	250 ppm
Manganese	HBSL	300 ppb	Chloride	SMCL	250 ppm
Uranium	MCL	30 ppb	Manganese	SMCL	50 ppb
Nitrate as nitrogen	MCL	10 ppm	Iron	SMCL	300 ppb
Gross-alpha activity	MCL	15 pCi/L	pH	SMCL	6.5–8.5

# Constituents With Moderate and High Concentration Vary by Region

Inorganic constituents with human-health benchmarks and constituents with secondary non-health benchmarks commonly were measured at high and moderate concentrations in the High Plains aquifer. The most prevalent of these constituents with moderate or high concentrations relative to human-health benchmarks were arsenic, fluoride, and uranium, and the most prevalent relative to secondary non-health benchmarks was TDS. The distribution of these constituents, however, varied across the Northern, Central, and Southern High Plains aquifer subregions. High concentrations of TDS, arsenic, and fluoride were most common in the Southern High Plains. High and moderate concentrations of uranium were less common overall but were, conversely, more common in the Northern High Plains. These differences in water quality across the High Plains aquifer might reflect differences in the composition of rocks and sediments that compose the aquifer, aquifer flow-path characteristics, aquifer geochemical conditions, and other factors. Previous studies have noted higher concentrations of constituents such as arsenic and fluoride that often correlate with higher TDS concentrations in the Southern High Plains and attributed the high concentrations to the upward movement of saline water from the underlying Dockum aquifer (Nativ and Smith, 1987; Scanlon and others, 2009). High concentrations of uranium have been previously noted throughout the High Plains aquifer and were correlated with nitrate concentrations, particularly in shallow groundwater (Nolan and Weber, 2015).

By MaryLynn Musgrove



# Principal Aquifer Surveys

The USGS NAWQA Project has been assessing the quality of groundwater since 1991. The NAWQA studies include Land Use Studies (LUS), Major Aquifer Studies (MAS), and Principal Aquifer Studies (PAS). These three study types are based on sampling networks of wells distributed across an area of interest. The LUS networks typically consist of observation wells that are relatively shallow; MAS networks typically consist of domestic-supply wells that are intermediate in depth; and PAS networks typically consist of public-supply wells that are relatively deep. A national synthesis of shallow and intermediate depth groundwater quality was reported by DeSimone and others (2014). A regional synthesis of water quality for the High Plains aquifer was reported by McMahon and others (2007) and Gurdak and others (2009). This fact sheet provides a summary of PAS data for 80 public-supply wells sampled in 2015 and 2016 in the High Plains aquifer (data available in Arnold and others, 2020b).

The PAS assessments like this one allow for the comparison of constituent concentrations in untreated groundwater with benchmarks established for the protection of human health and for aesthetic qualities of drinking water and also provide a basis for comparison of groundwater quality among the principal aquifers.

The data collected by the NAWQA Project include chemical analyses generally not available as part of regulatory compliance monitoring, including measurements at concentrations much lower than the levels used as human-health benchmarks and measurement of constituents that can be used to trace the sources and movement of groundwater.

## For more information

Technical reports and hydrologic data collected for the USGS NAWQA Project may be obtained from

**NAWQA Chief Scientist**  
 U.S. Geological Survey  
 12201 Sunrise Valley Drive, MS 413  
 Reston, VA 20192-0002  
 Email: [nawqapublicinfo@usgs.gov](mailto:nawqapublicinfo@usgs.gov)  
 WEB: <https://water.usgs.gov/nawqa/>

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