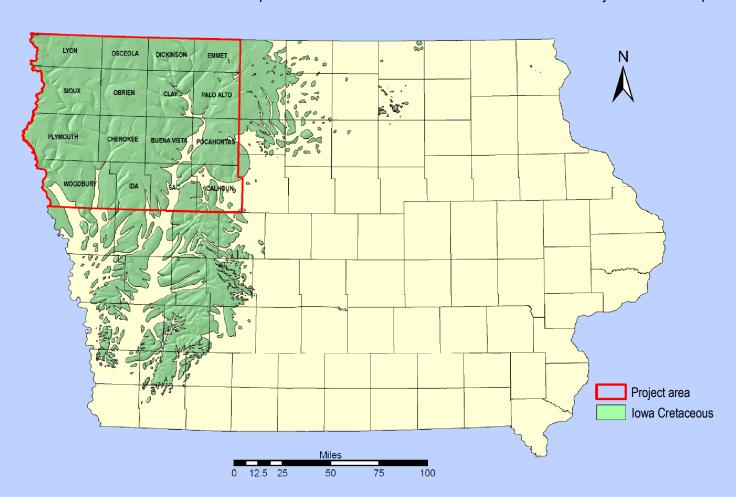
The Dakota Aquifer

The Dakota Aquifer is used for rural and public water supplies in western lowa. This aquifer is the youngest of the bedrock aquifers in Iowa and is composed of two members: the upper Woodbury Member consists of shales and very fine- to fine-grained sandstones, and the underlying Nishnabotna Member consists of fine- to very course grained sandstones. These deposits formed in riverine environments 100 million years ago. Woodbury rocks form a minor aquifer with low to moderate yields, while Nishnabotna rocks form a major aquifer capable of yielding greater than 1,500 gallons per minute (gpm) in some areas. Because of the greater continuous areal extent and higher yields, the initial water resource evaluations concentrated on the Dakota Aquifer within 16 counties in northwest Iowa.

For the Dakota Aquifer groundwater quality evaluation, the upper and lower members of the aquifer were not distinguished because there is currently not enough well data to determine if there are consistent differences in water quality between them. It appears that there are differences, and that a major factor influencing the water quality may be the depth of the aquifer and the type of materials overlying it. In general, the lower part of the Dakota has greater yield potential, but tends to exhibit poorer natural water quality. For practical purposes, domestic supplies often use the upper portion of the aquifer because drilling costs are lower, and they do not need large yields. Public and industrial users that need greater yields usually use the lower portion of the aquifer, even if the water quality is poorer.



Area of occurrence and significant use of the Dakota Aquifer in western Iowa (modified from Iowa's Groundwater Basics by Jean Prior, et al., 2003, Iowa Department of Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages).

The Dakota Aquifer groundwater quality evaluation focused on naturally occurring constituents, since anthropogenic, or man-made, contaminants are usually not found in water from the aguifer, because it is protected from surface contamination in most areas by thick overlying glacial drift and shales. Some Dakota wells penetrate the full extent of the aguifer and some are completed in only the upper part. As mentioned, private wells tend to be completed in the upper part, while public and industrial wells usually penetrate the full extent of the aguifer to obtain greater yields. Differences in water quality between the upper and lower parts of the aquifer may be significant in areas where the upper part of the aquifer is not protected from relatively rapid recharge of water by low-permeable materials like thick glacial tills and shales, while the lower part of the aquifer is protected by low-permeable shales and

To construct the following maps, water quality analyses were averaged for each well point location. The point locations were then converted to a grid using a topo to raster tool. The grid was clipped using the appropriate bedrock coverage and outline of the sixteen counties in northwest Iowa as a boundary condition. The grid was then contoured using a raster surface contour tool.

New Water Quality Database

The Dakota Aquifer groundwater guality evaluation is the first water resource study to use water-quality information from a new database that is available from the Iowa Geological and Water Survey's Natural Resources Geographic Information System (NRGIS) Library (www.igsb.uiowa.edu/nrgislibx/) as a downloadable shapefile named GW_Quality.zip. This GIS groundwater quality database, which can be thought of as a map layer, or coverage, was constructed to characterize lowa's aquifers and determine if contamination from human activity has increased in any of the aguifers in recent years. The database is divided into two separate map layers named "General" and "Contaminant." The General map layer contains naturally occurring constituents including metals, physical characteristics (total dissolved solids, pH, etc.), and radionuclides. The Contaminant map layer accommodates nutrients, man-made contaminants such as volatile organic compounds, and pesticides. The map layers include geographically indexed, or

geo-referenced, data from wells completed in all of Iowa's major aquifers. Together, the layers contain over 8,000 analyses of raw water, collected from over 2,000 wells, with a combined total of over 300 sampled parameters. The samples were collected over many years by numerous individuals from private, public, and government sectors from public and private wells across lowa. Most samples are from public water supplies and were analyzed by the University Hygienic Laboratory (UHL), but samples from a variety of projects, including aguifer and water studies, contaminant plume mapping, maximum contaminant level compliance monitoring, and analyses from other laboratories are also included in the map layers.

The General and Contaminant data sets each currently contain 728 different water guality analyses collected from 139 wells completed in the Dakota Aquifer within the study area in northeast lowa.

Water Quality Basics

Water quality is a major factor in the development of a water supply, and quality problems can arise from a multitude of sources, both natural and anthropogenic As groundwater moves through sediments and rocks, it dissolves some of the more soluble minerals, adding to the water's total dissolved solids (TDS). In general, deeper aquifers contain older groundwater that has been in contact with rocks longer, so they have higher concentrations of various dissolved solids. Carbonate minerals are the common and soluble, and contribute dissolved calcium (Ca), magnesium (Mg), and bicarbonate (HCO₃) to groundwater. Sulfur-bearing minerals like gypsum (CaSO4·2H2O) and pyrite (FeS2), while less common, add sulfate (SO4) to the water. Other minerals and buried organic matter can add dissolved or gaseous constituents such as iron (Fe), manganese (Mn), arsenic (As), hydrogen sulfide (H2S), ammonia (NH3), methane (CH4), and radioactive compounds like radium (Ra) and radon (Rn). Because water is an excellent solvent, it retains a signature of the geologic materials that it passes through over

time. These natural constituents can affect the taste, smell, and color of water, its usefulness for various purposes, and human and animal health.

Total dissolved solids are often used as an indicator of the aesthetic characteristics of drinking water and as an aggregate indicator of the presence of a broad array of chemical contaminants. For drinking purposes, water is considered good when it contains less than 500 mg/L of TDS, fair when it contains 500 to 1,000 mg/L, and poor when greater than 1,000 mg/L of TDS are present.

Although TDS are generally not considered a health hazard, water treatment is recommended when TDS concentrations exceed the EPA's 500 mg/L secondary maximum contaminant level (SMCL). If an exceedance occurs, further testing may be warranted, as water with high TDS may indicate elevated levels of ions, such as aluminum, arsenic, copper, lead, nitrate, and others that may be a health concern.

Commonly occurring constituents and their significance in drinking water (modified from Iowa's Groundwater Basics by Jean Prior, et al., 2003, Iowa Department of

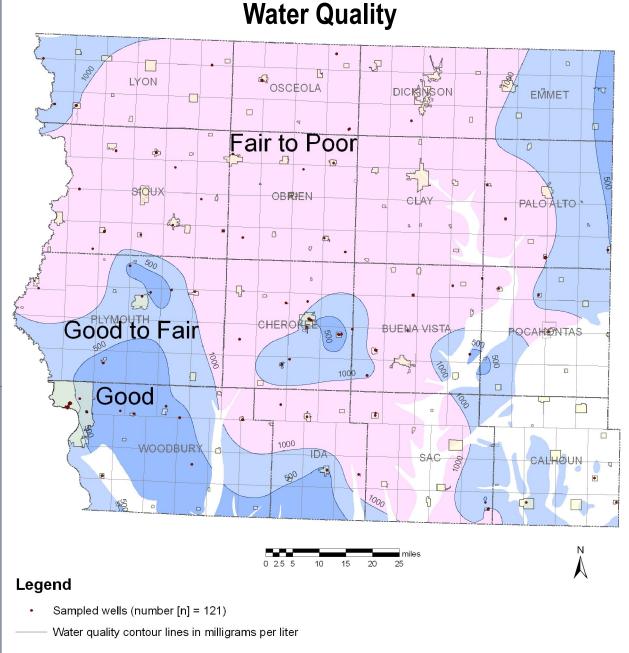
Constituent or Property	Maximum contaminant level (MCL) for public water supplies	Recommended maximum level	Constituent naturally occurring	Comments			
Microorganisms Total Coliform bacteria	No bacteria in 95% of samples collected		•	Indicates pathway for potentially harmful microorganisms; inadequate well condition; possibly faulty well construction			
Inorganic chemicals Arsenic (As)	0.01 mg/L		•	Can cause adverse health effects; carcinogenic			
Chloride (CI)		250 mg/L	•	Salty taste when sodium is present; corrosion of pipes			
Fluoride (F)	4.0 mg/L	2.0 mg/L	•	Affects dental health; >2 mg/L causes mottling of teeth enamel			
Hardness as CaCO ₃ ; Calcium (Ca) and Magnesium (Mg)			•	Limits lathering ability of soap; causes scale buildup; water becomes objectionable for domestic use when >100 mg/L			
Iron (Fe)		0.3 mg/L	•	Objectionable taste; stains laundry and porcelain			
Manganese (Mn)		0.05 mg/L	•	Objectionable taste; stains laundry and porcelain			
Nitrate: as N as NO ₃	10 mg/L 45 mg/L		•	Land-applied fertilizer; leaching from septic tanks and sewage; adverse health effects; causes "blue baby syndrome" in infants			
Sodium (Na) and Potassium (K)			•	Salty taste when combined with chloride; sodium salts cause foming in boilers; consult physician if on a low sodium diet			
Sulfate (SO ₄)		250 mg/L	•	Objectionable taste; >750 mg/L causes laxative effects; forms scale when combined with calcium			
Total dissolved solids (TDS)		500 mg/L	•	Refers to all material in solution; limits lathering of soap; objectionable taste; >2,000 mg/L causes laxative effects			
Suspended sediment			•	Gives water a muddy or turbid appearance; causes pump wear			
Dissolved gases Hydrogen sulfide (H ₂ S) Methane (CH ₄)			•	Causes rotten egg odor; corrosion of pipes, casing and pumps Explosive, flammable			
Common ions Bicarbonate (HCO ₃)			•	Contributes to the alkalinity of water; principal ion in fresh water			
Carbonate (CO ₃)			•	Contributes to the alkalinity of water; seldom present in fresh water			
Radionuclides	45.00						
Gross alpha particles	15 pCi/L		•	Formed by decay of radioactive elements; adverse health effects			
Beta particles	4 millirems/year		•	Formed by decay of radioactive elements; adverse health effects			
Radium 226 & 228 (Ra)	5 pCi/L (combined)		•	Formed by decay of radioactive elements; adverse health effects			
Radon 222 (Rn)	4000 pCi/L		•	Colorless gas formed by decay of radium; adverse health effects			
Organic chemicals Pesticides	Atrazine 0.003 mg/L Alachlor 0.002 mg/L			Land-applied herbicides; causes adverse health effects			
Benzene	0.005 mg/L			Leaking gasoline storage tanks; causes adverse health effects			
Trichloroethylene (TCE)	0.005 mg/L			Industrial solvent and degreaser; causes adverse health effects			
Temperature			•	Affects the desirability and economy of water use for cooling			
рН	6.4 to 10.0 pH units	6.5 to 8.5 pH units	•	Acid-base balance of water; values < 7 are acidic, > 7 are basic			
Specific conductance		1,600 µmhos/cm	•	Capability to carry electrical current or content of dissolved mineral			
mg/L = milligrams per liter;	ng/L = milligrams per liter; equivalent to parts per million pCi/L = picocuries per liter µmhos/cm = micromhos per centimeter						
For further information: lowa's	Groundwater Basics by Jean C.	Prior, et al., Iowa Depa	artment of Natu	ral Resources, Iowa Geological Survey Educational Series 6, 83 pages.			

The preceding table summarizes some commonly occurring chemical constituents and properties that can cause problems in Iowa's drinking water. Contaminants that affect health must meet legally enforceable primary Maximum Contaminant Level (MCL) standards for public water supplies, while contaminants that affect the aesthetic quality of water are unregulated and use SMCLs to define acceptable levels of contamination based on taste, odor, color and certain other non-aesthetic effects of drinking water. Contaminants that affect health include bacteria, nitrate (NO3), pesticides, radionuclides, organic chemicals, arsenic (As), and lead (Pb).

Contaminants that affect the aesthetic quality of water, but do not affect health, at least in small quantities, include sulfate, total dissolved solids, calcium, magnesium, hydrogen sulfide, iron, manganese, and iron bacteria. SMCLs for these constituents are often exceeded for long periods without obvious detrimental effects, although the water may have a bad odor and be unpalatable. In many areas, the best water that is locally available may have aesthetic problems, but still be widely used. For constituents that affect health, the regulated MCLs can not be exceeded legally, even for short periods.

Publications about water quality and its effects on health are available from the U.S. Environmental Protection Agency (USEPA) at www.epa.gov/safewater/, the U.S.Geological Survey (USGS) at water.usgs.gov/owq/, and the Iowa Geological and Water Survey at www.igsb.uiowa.edu/service/wateres.htm.

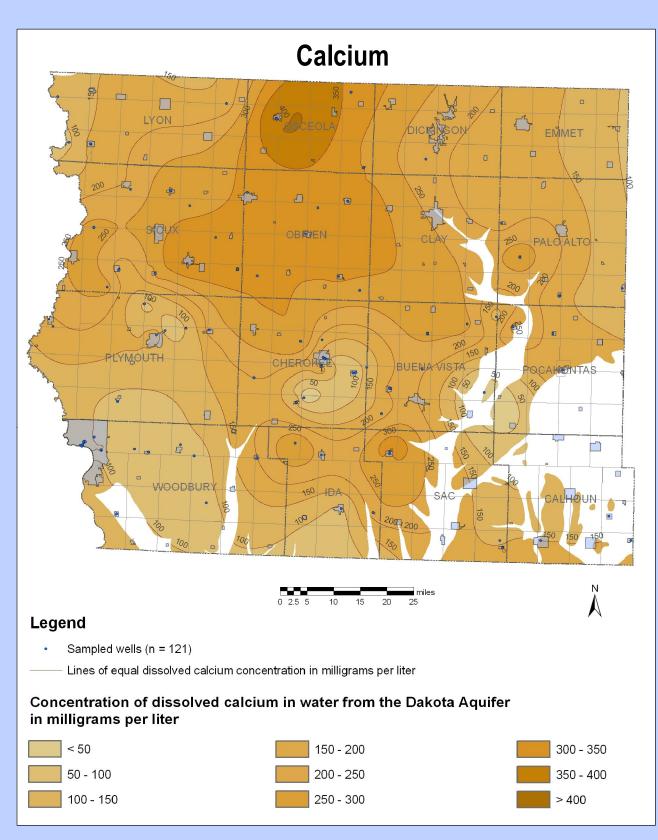
Water Quality of the Dakota Aquifer



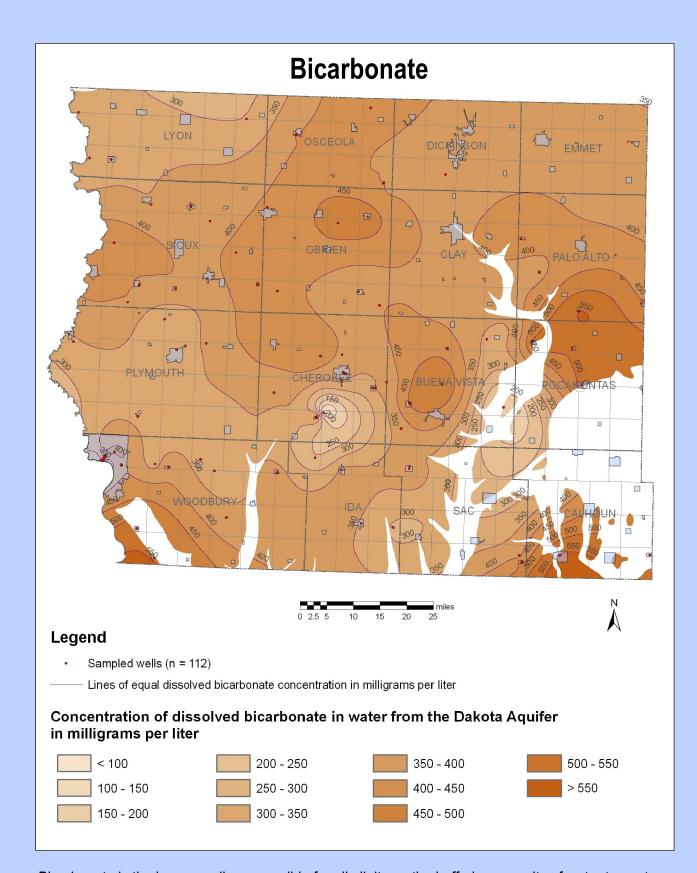
Concentration of total dissolved solids in water from the Dakota Aquifer in milligrams per liter

< 500 Water quality is good</p> 500 - 1,000 Water quality is good to fair > 1,000 Water quality is fair to poor

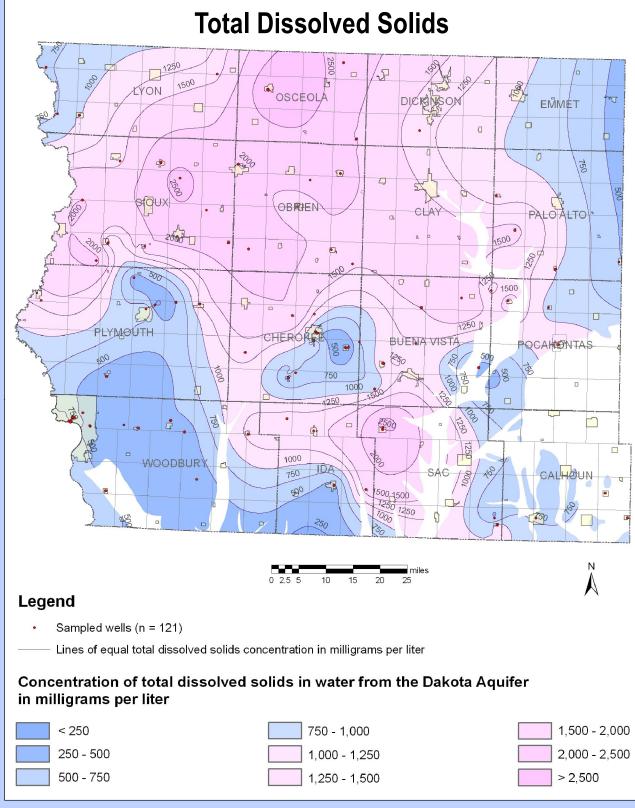
The water quality of the Dakota Aquifer tends to be fair to poor throughout most of the study area and good to fair towards the corners of the study area. The areas of poorer water quality result from high concentrations of TDS (between 1,000 and 3,000 mg/L), particularly sulfate and calcium carbonate, which are common minerals picked up by groundwater in contact with the confining layers above. Areas of better water quality are found where confining layers are thin and porous pathways allow for more rapid recharge by less mineralized, younger water. This occurs most notably in the southwest, southeast, and northeast portions of the study area where the aquifer is closer to the land surface.



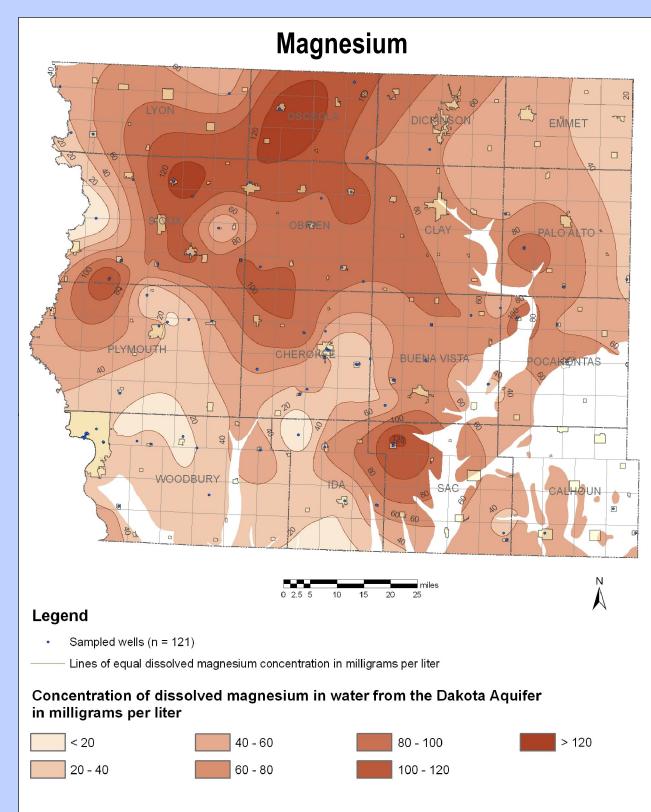
Hard water minerals primarily consist of calcium, and magnesium metal cations, and sometimes other dissolved compounds such as bicarbonates and sulfates. Calcium usually enters the water as either calcium carbonate, from the dissolution of limestone and chalk, or calcium sulfate, from the dissolution of anhydrite. Currently there is no MCL or SMCL for calcium for public water supplies.



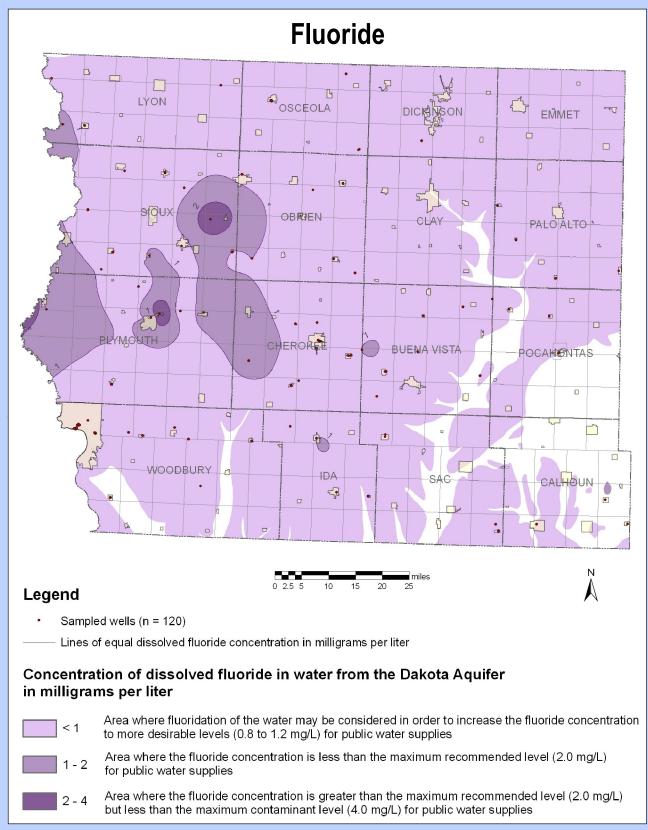
Bicarbonate is the ion normally responsible for alkalinity, or the buffering capacity of water to neutralize acids or resist changes in pH. It is a natural corrosion inhibitor in soft water systems. Bicarbonate alkalinity is introduced into the water by carbon dioxide dissolving carbonate-containing minerals and rocks like calcite and dolomite. Alkalinity control is important in boiler feed water, cooling tower water, and in the beverage and textile industry. In a pH range of 5.0 to 8.0, there is a balance between excess carbon dioxide and bicarbonate ions. Removing free carbon dioxide through aeration can reduce bicarbonate alkalinity. Feeding acid into the water to lower the pH can also reduce alkalinity. At a pH of 5.0, there is only carbon dioxide and no alkalinity. A strong base anion exchanger will also remove alkalinity. Currently there is no MCL or SMCL for bicarbonate for public water supplies.



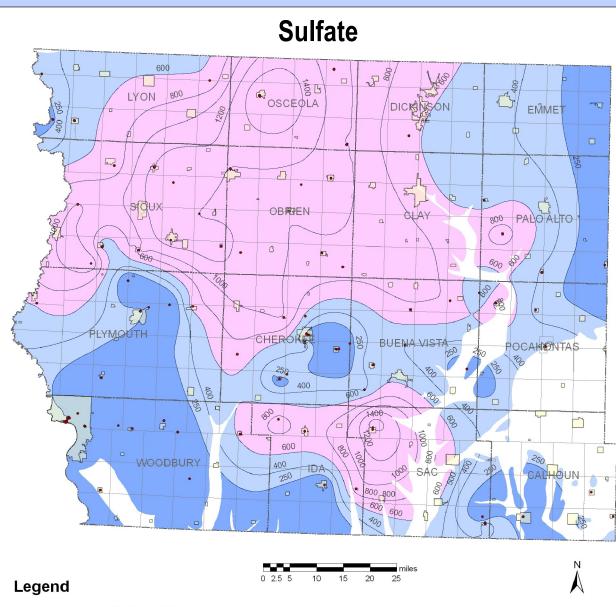
Significant differences in water quality have been found in wells located in near proximity to each other that are completed in different members of the aquifer. Interbedded shales, silts, and fine grained sandstones appear to be separating older, more mineralized water in the Nishnabotna Member from relatively younger, less mineralized water in the Woodbury Member. Treatment options for TDS depend on the nature of the cations and anions present in the water. For example, a water softener can reduce problems associated with calcium, magnesium, and iron, while reverse osmosis or distillation may be recommended to treat elevated TDS levels associated with high levels of sodium or potassium. Carbon filtration and electrodialysis are also effective in removing TDS from drinking water.



The predominant source of magnesium in groundwater is dolomite, which is a sedimentary rock sim-ilar to limestone. Dolomite differs from limestone, CaCO₃, by the addition of magnesium to make the formula, CaMg(CO₃)². Magnesium and calcium can be removed from water by softening. There is currently no MCL or SMCL for magnesium for public water supplies.



Fluoride is a common constituent of many minerals like fluorspar and apatite. It is the reduced form of fluorine. Water treatment plants commonly add fluoride to finished water for prevention of tooth decay, and generally maintain a level of 1.5 to 2.5 mg/L. Concentrations of fluoride above 5 mg/L are harmful to tooth structure. In the Dakota Aquifer, elevated concentrations of dissolved fluoride are usually associated with sodium-bicarbonate waters. The high fluoride concentrations are probably derived from the dissolution of apatite minerals. Fluoride can be reduced in drinking water by reverse osmosis, anion exchange, and distillation. Adsorption by calcium phosphate, magnesiumiydroxide, or activated carbon will also reduce the fluoride content of drinking water. Reverse osmosis will remove 93 to 95% of the fluoride. Currently the MCL for fluoride is 4.0 mg/L for public water supplies.



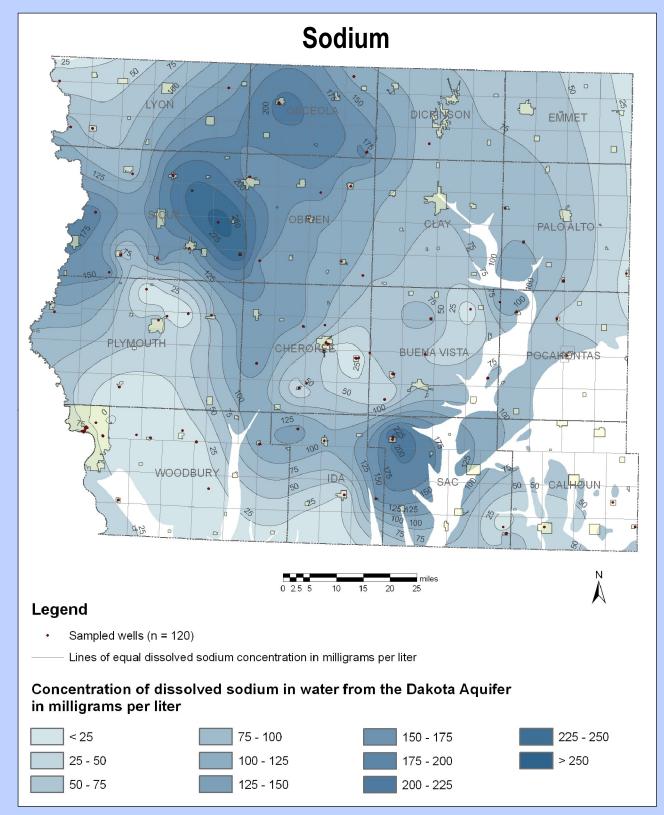
Sampled wells (n = 121) - Lines of equal dissolved sulfate concentration in milligrams per liter

Concentration of dissolved sulfate in water from the Dakota Aquifer in milligrams per liter

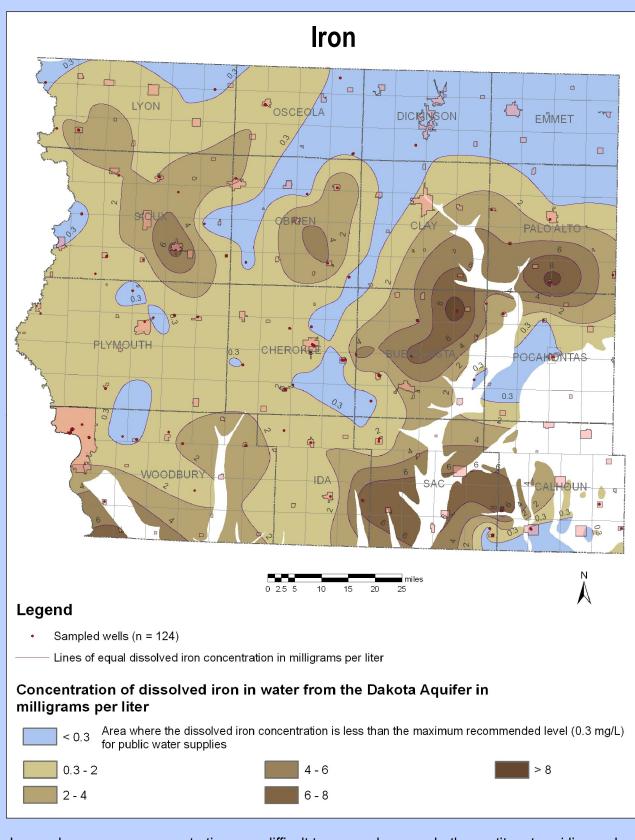
Area where the sulfate concentration is less than the maximum recommended level proposed for public water supplies Area where the sulfate concentration is more than the maximum recommended level but 250 - 600 considered acceptable because most users can adjust to it > 600 Area where sulfate concentration is high enough to affect the taste of water and also have

a laxative effect Sulfate (SO4) occurs naturally in Iowa's deeper groundwater. It results from the dissolution of soil and rock formations that contain sulfate minerals, like pyrite (FeS2). At elevated levels, sulfate can give

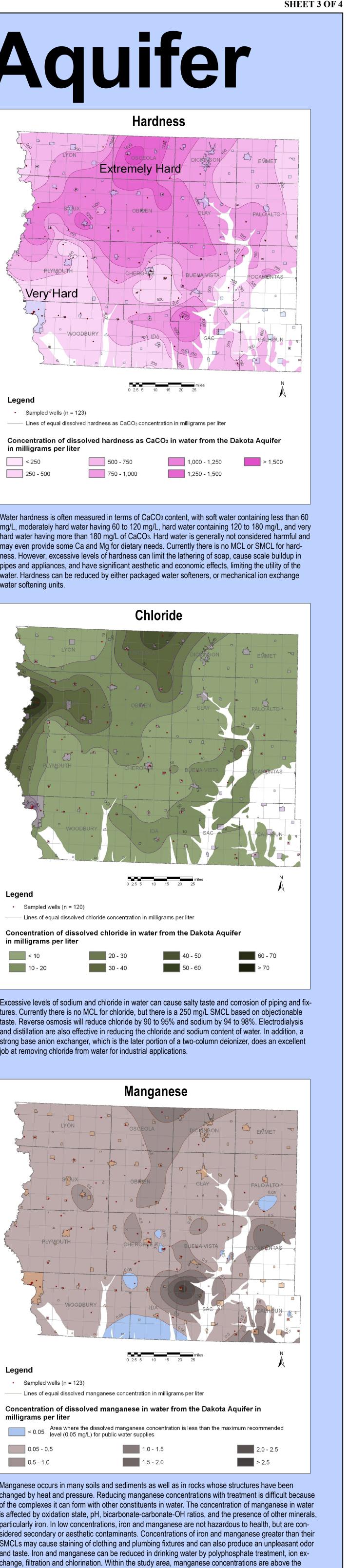
water a bitter or astringent taste and may cause corrosion of plumbing, particularly copper piping. Health concerns regarding sulfate in drinking water have been raised because diarrhea may be associated with the ingestion of water containing high levels of sulfate. The EPA currently has a SMCL of 250 mg/L for sulfate based on aesthetic metrics such as taste and odor. Reverse osmosis, ion exchange, and distillation will remove sulfate from drinking water, while softening and filtration will not.



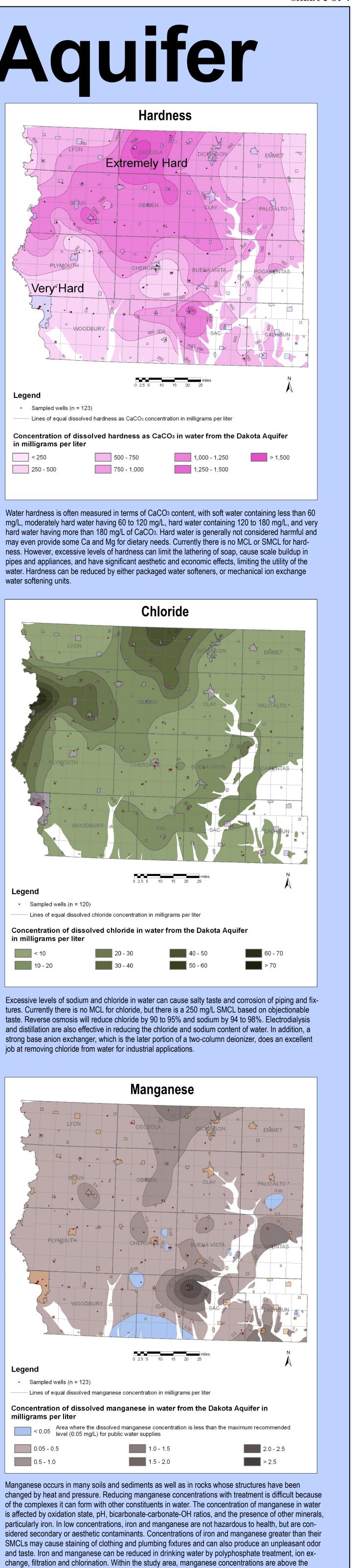
The past occurrence of saline water in Dakota Aquifer strata, from dissolution of rock salt in areas with underlying Permian rocks, resulted in the adsorption of large amounts of sodium on clays within Dakota rocks. In areas where freshwater slowly flushes saline water from the aquifer, a process of natural softening may be occurring. This may increase dissolved sodium and bicarbonate while decreasing dissolved calcium, magnesium, and chloride in some parts of the aquifer. There is no MCL or SMCL for sodium for public water supplies, but there is a 20 mg/L EPA guidance level.

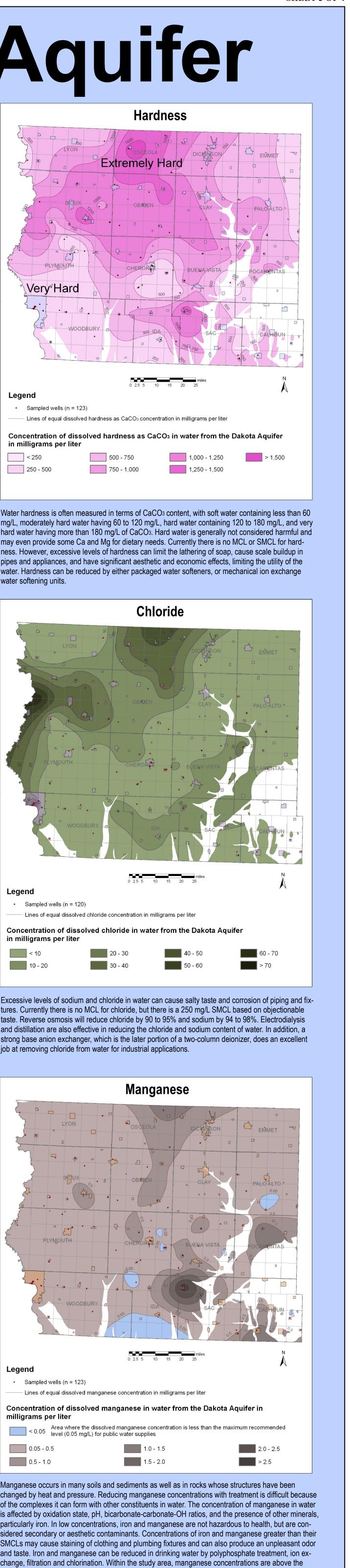


Iron and manganese concentrations are difficult to assess because both constituents oxidize and precipitate readily in the presence of air. Unless special sampling procedures are used, concentrations reported from water analyses can be very different from concentrations found in the aquifer. In addition, iron dissolution from the well casing and distribution system can increase the iron content of the water. High iron concentrations occur in outcrop or subcrop areas where recharge with dissolved oxygen oxidizes pyrite, producing sulfate and iron. High iron concentrations also exist in the confined portion of the aquifer where the water is ancient and no recent recharge with significant oxygen can enter. The reducing environment allows iron, manganese, and some other heavy metals to dissolve from the sediments. Dissolved iron concentrations are above the 0.3 mg/L SMCL for iron throughout much of the Dakota Aquifer study area.



MISCELLANEOUS MAP SERIES 11





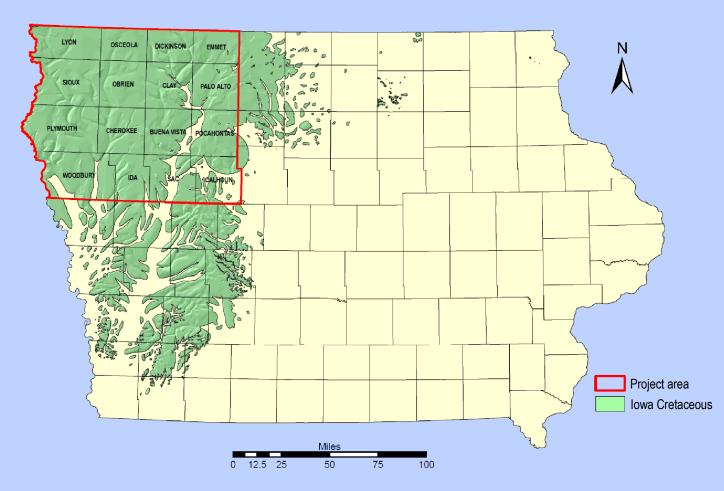
0.05 mg/L SMCL for public water supplies everywhere except for a few localized areas.

Radioactivity and Groundwater

Radioactivity is the process whereby unstable atomic nuclei, or radionuclides, release energetic subatomic particles. There are three major types of radiation that may be released: alpha particles, beta particles, and gamma rays. These are positively charged, negatively charged, and neutral, respectively. Natural radiation comes from cosmic rays from space and naturally occurring radioactive materials that exist in rocks, soil, food, water, and air in our environment. Human exposure to radioactivity is sometimes measured in rads, where one rad represents 0.01 joule of energy absorbed per kilogram of tissue.

Radium (Ra) is a radioactive metal that occurs naturally in trace amounts in rocks, soils, and groundwater. As radium decays, it continually releases energy in the form of alpha particles, beta particles, and gamma rays, as well as radon (Rn) gas, which are part of the natural radiation to which all life is exposed. Radium readily dissolves in groundwater, especially in areas where acidic conditions (low pH levels) occur. Radioactive decay is often measured in picocuries (pCi), where one pCi is equivalent to 0.037 nuclear disintegrations per second.

Limited Radionuclide Data Set



Area of occurrence and significant use of the Dakota Aquifer in western Iowa (modified from Iowa's Groundwater Basics by Jean Prior, et al., 2003, Iowa Department of Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages).

Within the study area, fewer samples have been analyzed for radionuclides than for other constituents, in part, because radionuclides are often analyzed using a screening procedure. For samples in the data set from a joint USGS-IGWS water quality study, when gross alpha activity exceeded 5 pCi per liter (pCi/L), an equivalent sample was analyzed for raduim-226. Then, if the radium-226 concentration exceeded 3

pCi/L, an equivalent sample was analyzed for radium-228. Within the entire general data set, there were 17 samples analyzed for tritium, 24 samples for radon-222, 36 samples for radium-228, 73 samples each for gross alpha and gross beta activity, and 152 samples were analyzed for radium-226.

For mapping purposes, sampled constituents yielding results below method quantitation limits were assigned a concentration equal to one half of the value of the quantitation limit of the constituent at the time of sampling. These values were then plotted and used for contouring if they were the only analysis of the constituent from a well. For wells with multiple occurrences of the same constituent from different analyses, the constituent concentrations were averaged and then plotted and contoured. The accuracy of contouring of the radionuclide maps in this report, especially those based on fewer well samples, would benefit from a larger and better distributed data set.

Factors Determining Radioactivity in Groundwater

Most radionuclides in groundwater result from contact of the water with rocks. The content of these elements in groundwater and hence the levels of radioactivity depend on a combination of several factors, including the concentrations of these elements in the aquifer rocks, chemical reactions, and the physical processes of decay, along with the flow rate and age of the groundwater.

One factor determining the occurrence of radioactivity in groundwater is geology. Abundance of parent elements of the decay products is typically associated with high activity of one or several radionuclides in the associated groundwater. Sedimentary rocks, such as shale and phosphate are predominantly enriched in uranium and thus the decay product of the uranium decay chain, radium-226, characterizes the associated groundwater. Similarly, rocks such as granite are enriched in uranium and thorium, therefore associated groundwater contains their decay products, radium-226 and radium-228.

A factor that controls mobilization of radionuclides from aquifer rocks is the chemical condition of the groundwater, which can result in significant leaching of these elements into groundwater. In particular, levels of acidity (pH), salinity, temperature, and oxidation of groundwater affect radionuclide mobilization. In addition, the geochemical properties of each radionuclide determine its availability in water. Radium, for example, can be kept out of groundwater by sorption onto clay minerals, precipitation with secondary minerals, and radioactive decay. Many studies have shown that an exchange reaction with clay minerals is the predominant process that controls radium activity in low-saline groundwater.

High radium levels in wells in some agricultural areas have been associated with agricultural recharge, which induces nitrification and reduces pH. This enhances the extraction of radium from exchange sites on clay minerals, and consequently increases the radium levels in the associated groundwater. Since pollution from nitrate is one of the most frequent forms of groundwater contamination worldwide, additional side effects, such as the formation of acidic water and the rise of radionuclides in groundwater, may have severe consequences in the future.

Salinity appears to play a major role in radium distribution. Groundwater from aguifers in parts of the Midwest shows an almost linear correlation between radium-226 and salinity. Generally, in freshwater conditions, most of the radium remains in the aquifer rocks, while in saline conditions the radium escapes from the rocks and results in high concentrations in groundwater.

Groundwater with no oxygen is typically enriched in radium. The increased radium activity in oxygen-free water is thought to come from the mobilization of

manganese. With oxygen present, radium strongly bonds to manganese oxide, but in oxygen-free conditions, manganese oxide is no longer stable, and both radium and manganese are released into the associated groundwater.

Temperature is also an important factor that enhances radium leaching from rocks, and since temperature increases with depth, deeper wells generally have greater radium concentrations, if parent materials are present. In addition, because radium leaching from rocks is enhanced by both temperature and salinity, mineralized thermal springs that are used as a source of bottled mineral water may have high concentrations of radium.

Additional factors affecting the movement of radionuclides into groundwater are the age of the groundwater and the physical relationship between the decay rates of the radionuclides and the flow rate of the groundwater. In general, older groundwater has been in contact with the geologic parent materials longer, allowing more time to accumulate radioactive decay products. In like manner, slower groundwater flow rates encourage greater enrichment of both short- and long-lived radionuclides, since slower moving groundwater is in contact with the radionuclides longer.

The following table summarizes some commonly occurring radionuclides, isotopes and properties that can cause problems in Iowa drinking water. Contaminants that affect health must meet legally enforceable primary Maximum Contaminant Level (MCL) standards for public water supplies, while contaminants that affect the aesthetic quality of water are unregulated and use Secondary Maximum Contaminant Levels (SMCLs) to define acceptable levels of contamination based on taste, odor, color and certain other non-aesthetic effects of drinking water. Contaminants that affect health include radionuclides and isotopes.

A property that affects the aesthetic quality of water, but does not affect health, is temperature. SMCLs for many constituents are often exceeded for long periods without obvious detrimental effects, although the water may have a bad odor and be unpalatable. In many areas, the best water that is locally available may have aesthetic problems, but still be widely used. For constituents that affect health, the regulated MCLs can not be exceeded legally, even for short periods.

Publications about water quality and its effects on health are available from the U.S. Environmental Protection Agency (USEPA) at www.epa.gov/safewater/, the U.S.Geological Survey (USGS) at water.usgs.gov/owq/, and the Iowa Geological and Water Survey at www.igsb.uiowa.edu/service/wateres.htm.

Commonly occurring radionuclides, isotopes and temperature, and their significance in drinking water (modified from Iowa's Groundwater Basics by Jean Prior, et al., 2003, Iowa Department of Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages).

Constituent	Maximum	Recommended	Constituent			
or	contaminant level (MCL)	maximum	naturally	Comments		
Property	for public water supplies	level	occurring			
Radionuclides Gross alpha particles	15 pCi/L		•	Formed by decay of radioactive elements; adverse health effects		
Gross beta particles	4 millirems/year		•	Formed by decay of radioactive elements; adverse health effects		
Radium 226 & 228 (Ra)	5 pCi/L (combined)		•	Formed by decay of radioactive elements; adverse health effects		
Radon 222 (Rn)	4000 pCi/L		•	Colorless gas formed by decay of radium; adverse health effects		
Isotopes Tritium (³ H)			•	Radioactive isotope of hydrogen; adverse health effects		
Temperature			•	Affects the desirability and economy of water use for cooling		
pCi/L = picocuries per liter						

Isotopes and Tritium

For further information: Iowa's Groundwater Basics by Jean C. Prior, et al., Iowa Department of Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages.

Isotopes are forms of the same element that have different numbers of neutrons in the nucleus. Tritium is the common name for hydrogen-3 (³H), which is a radioactive isotope of hydrogen (H). Like ordinary hydrogen (¹H) and deuterium (²H), tritium has a single proton in its nucleus. Unlike ordinary hydrogen, deuterium has one neutron and is stable, while tritium contains two neutrons and is unstable. Tritium decays spontaneously to helium-3 (³He) through ejection of a beta particle and has a half-life of 12.32 years. Tritium behaves like ordinary hydrogen and can replace it in water molecules so it readily cycles through hydrologic and biologic environments.

The unit of measure of tritium in water is the tritium unit (TU), which equals 1 tritium atom in 1,018 hydrogen atoms. In picocuries per liter (pCi/L), 1 TU is 3.19 pCi/L. Tritium occurs in very small quantities naturally, as it is produced in the upper atmosphere by cosmic rays. Natural levels of tritium in precipitation are on the order of 1 to 5 TU, or about 3.2 to 16 pCi/L. Nuclear-weapons testing during the 1950s and 1960s created relatively large amounts of tritium in the atmosphere, so tritium can be used to estimate whether groundwater has been recharged before or after about 1953. The amount of tritium in infiltrating precipitation that becomes groundwater recharge is controlled primarily by the amount of tritium in the atmosphere when the precipitation formed, plus the length of time it takes for water to move from the land surface into an aquifer. Because tritium decays with a half-life of 12.32 years, groundwater that contains low levels of tritium is inferred to have infiltrated into the subsurface prior to 1953. Conversely, groundwater that contains tritium concentrations greater than natural background

levels is inferred to contain at least some water that infiltrated after 1953. Because tritium is decaying rapidly, it is becoming more difficult to use bomb tritium to date the age of groundwater, however, scientists can also use the ratio of tritium to its decay product helium-3 (³He) to date groundwater (the time since the water last equilibrated with the atmosphere). The ³H/³He dating method can be used to date groundwater recharged within the past 30 years, but no further out than about 50 vears, and has an accuracy of one to three years.

Because tritium concentrations vary both spatially and temporally, it is important to establish the nearest precipitation measurement point to provide a reference to estimate groundwater recharge and travel times. Groundwater age estimation using tritium only provides semi-quantitative values:

- <3 pCi/L indicates submodern water (prior to 1950s)
- 3 to 13 pCi/L indicates a mix of submodern and modern water • 16 to 48 pCi/L indicates modern water (<5 to 10 years)
- 48 to 96 pCi/L indicates some bomb tritium • >96 pCi/L indicates recharge occurred in the 1960s to 1970s

Tritium is typically measured by a liquid scintillation counter. Tritium and ³He can be measured by mass spectrometry, but dissolved gases such as H₂O, CO₂, O₂, and N² must first be removed, generally by exposure to heated titanium. Sample costs vary from about \$300 per sample for tritium alone to \$1,000 per sample for 3 H/ 3 He depending on the laboratory.

Radon Gas

concentrations of uranium and thorium, the parent compounds of radium, were 50 and 11.4 ppm, respectively.

Radon gas typically moves up through the ground into the air above and into buildings through cracks and holes in foundations. The radon becomes trapped in buildings where it can build up. Any building may have a radon problem, and of the two main sources for radon in a building's indoor air, the radon entering a building through the soil is usually a much greater risk compared with the radon that may enter the building through tap water.

Radon (Rn) is a naturally occurring gaseous radioactive element formed by the atomic disintegration of radium. It is estimated to cause thousands of deaths each year by people breathing it, and is the second leading cause of lung cancer in the United States. Radon-222 (Rn²²²) is one of the radionuclides of most concern when found in drinking water.

Radon comes from the natural decay of radium that is found in nearly all soils. A geochemical survey of lowa that was conducted in cooperation with the USGS shows that from 1,063 shallow soil samples collected across lowa, the average

Water Quality of the Dakota Aquifer

Alpha Particles

Alpha particles are a type of ionizing radiation ejected by the nuclei of some unstable atoms. They are large subatomic fragments consisting of 2 neutrons and 2 protons with a charge of +2. Elements that emit alpha particles include actinium, americium-241, plutonium-236, uranium-238, thorium-232, radium-226, radon-222, and polonium-210. Since the number of protons in the nucleus of an atom determines the element, the loss of an alpha particle changes the parent atom to a different element. Most alpha emitters occur naturally in the environment.

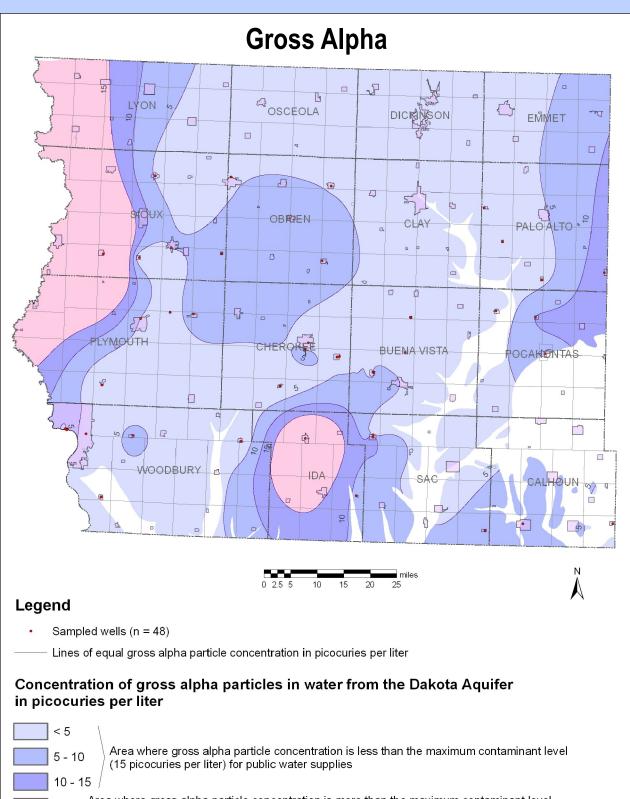
The positive charge of alpha particles is sometimes used in medical and industrial processes. Radium-226 may be used to treat cancer, by inserting tiny amounts of radium into a tumorous mass. Polonium-210 is used as a static eliminator in paper mills and other industries. The alpha particles, due to their positive charge, attract loose electrons, thus reducing static charge. Some smoke detectors employ alpha emissions from americium-241 to help create an electrical current. When smoke particles enter the device, the charged particles attract them, breaking the current and setting off the alarm.

Alpha particles are present in varying amounts in most rocks, soils, and water. However, human activity, can create or worsen the potential for exposure and contamination of various environmental media. Uranium mining wastes have high concentrations of uranium and radium. Once brought to the surface. they can be become airborne or enter surface water as runoff. Radioactivity associated with phosphate mining is concentrated in clays and sand tailings created by mining operations. These materials can accumulate in plants, animals and humans. Studies have indicated that phosphate mining may be related to an increased risk of leukemia, lung cancer and colon cancer.

Most naturally occurring radioactive elements emit alpha particles as they decay. Gross alpha radioactivity is a measurement of all alpha activity present, regardless of specific radionuclide source. Gross alpha activity is often used as a less expensive screening tool for determining the level of radium in drinking water. The detection of alpha particles in well water signals the presence of specific radioactive substances, and in the Midwest, it is often radium. There are other radioactive substances besides radium that may contribute to the gross alpha radiation in water, but analyses for these substances are usually not necessary because they are much less common locally.

The results of a gross alpha test can be used to determine if additional tests for radionuclides are needed. If short-term gross alpha test concentrations are less than 5 pCi/L, then no additional tests are necessary because the water meets safety requirements. Whenever test concentrations exceed 5 pCi/L, but are less than 15 pCi/L, then combined radium tests may be needed, and in the event that short-term gross alpha activity exceeds 15 pCi/L, the result indicates an exceedance of the MCL for gross alpha particles and suggests that further testing for specific alpha emitters should be conducted.

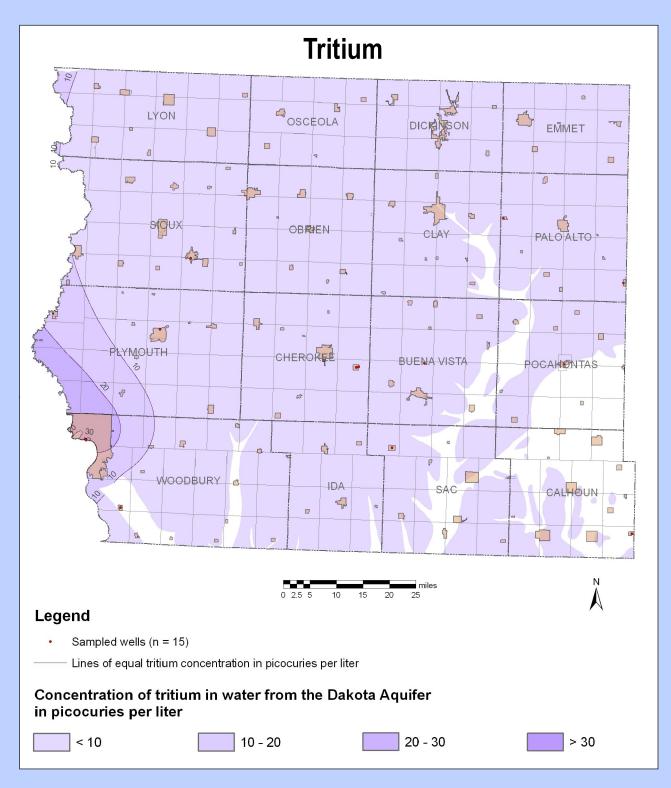
External exposure to alpha particles is of far less concern than internal exposure, because alpha particles can not penetrate the outer layer of dead skin. However, if alpha emitters are inhaled, ingested or absorbed into the blood stream, sensitive tissue can be exposed to alpha radiation. The resulting biological damage increases the risk of cancer. In particular, alpha radiation is known to cause lung cancer in humans when alpha emitters are inhaled. The greatest exposure to alpha radiation for most people comes from the inhalation of radon and its decay products, several of which also emit alpha



Area where gross alpha particle concentration is more than the maximum contaminant level

> 1 (15 picocuries per liter) for public water supplies

Distribution of gross alpha particles in water from the Dakota Aquifer in northwest Iowa. Within the study area, gross alpha particles were detected in sixty- five of seventy-three samples, with concentrations ranging from less than 1 to 44 pCi/L. Six samples were above, and one equaled, the 15 pCi/L MCL for gross alpha particles. Softening, anion exchange, acid neutralization and cation exchange are methods used to remove gross alpha particles from drinking water.



Distribution of tritium, in pCi/L, in water from the Dakota Aguifer in northwest Iowa. Within the study area, the only detected concentrations of tritium greater than 10 pCi/L were from Sioux City municipal wells. These wells are all located very near the Missouri River, in an area where the alluvial sands and gravels associated with the river directly overlie the Dakota Aquifer. It is probable that the aquifer is receiving relatively rapid recharge of tritiated water from the overlying alluvium in this area. The next highest tritium concentrations detected were less than 2 pCi/L, and were found in Aurelia municipal wells. The extent of water with tritium concentrations greater than 10 pCi/L is probably exaggerated by the contouring of the small data set. The actual extent is most likely limited to areas where the Dakota is rapidly recharged by Missouri River alluvium.

Beta Particles

Beta particles are subatomic particles that are ejected from the nucleus of some radioactive atoms. They are equivalent to electrons and have a charge of -1, but unlike electrons, which originate outside of the nucleus, beta particles originate in the nucleus. Elements that emit beta particles include tritium, cobalt-60, strontium-90, technetium-99, iodine-129 and -131 and cesium-137. A geochemical survey of Iowa that was conducted in cooperation with the USGS shows that from 1,063 shallow soil samples collected across lowa, the average concentrations of cobalt and strontium were 9.5 and 132 ppm, respectively.

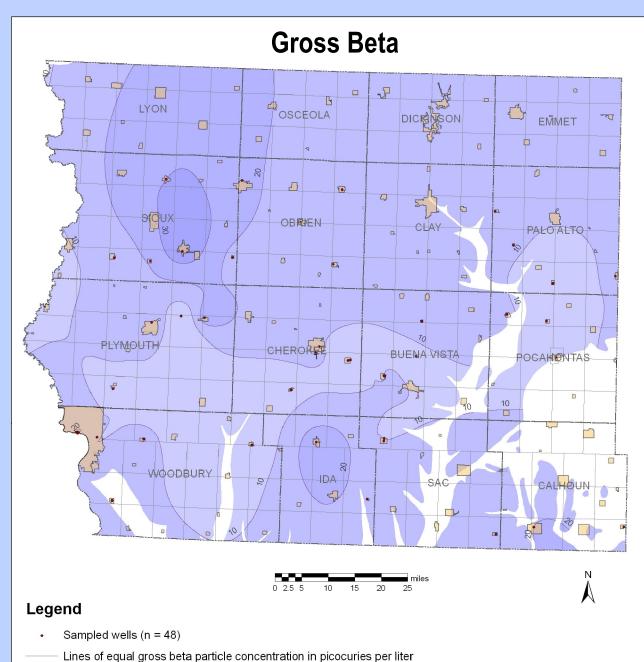
While beta particles are emitted by atoms that are radioactive, the beta particles themselves are not radioactive. It is their energy, in the form of speed that causes harm to living cells. When transferred, this energy can break chemical bonds and form ions. Beta particle emissions occur when the ratio of neutrons to protons in a nucleus is too high. Scientists think that an excess neutron transforms into a proton and an electron, and the proton stays in the nucleus while the electron is ejected. Since the number of protons in the nucleus of an atom determines the parent element, the conversion of a neutron to a proton changes the radionuclide to a different element.

There are both natural and anthropogenic radionuclides that emit beta particles. Potassium-40 and carbon-14 are weak beta emitters that are found naturally in the human body. Some decay products of radon also emit beta particles, but its alpha-emitting decay products pose a much greater health risk.

Like gross alpha activity, gross beta activity can be used as a less expensive screening tool for determining the level of radionuclides in drinking water. The detection of beta particles in well water signals the presence of specific radioactive substances. If short-term gross beta test levels are less than 5 pCi/L, then no additional tests are needed because the water meets safety requirements. In the event that beta particle test levels exceed 5 pCi/L, but are less than 50 pCi/L, then testing for specific beta emitters may be needed, and whenever short-term gross beta activity exceeds 50 pCi/L in a public water supply, the sample must be analyzed for major radioactive constituents. Direct exposure to beta particles can redden or burn the skin. However, emissions from inhaled or

ingested beta particle emitters are of much greater concern. Beta particles released directly into living tissue can cause damage at the molecular level and can disrupt cell function. Because they are much smaller and have a lower charge than alpha particles, beta particles generally travel further into tissues. As a result, the cellular damage is more dispersed. Beta radiation can cause both acute and chronic health effects, although acute exposures are uncommon. The chronic effects result from low-level exposure over a long period of time (5 to 30 years), with the main chronic health effect from radiation being cancer. When taken internally beta emitters can cause tissue damage and increase the risk of cancer, with the risk increasing with increasing dosage.

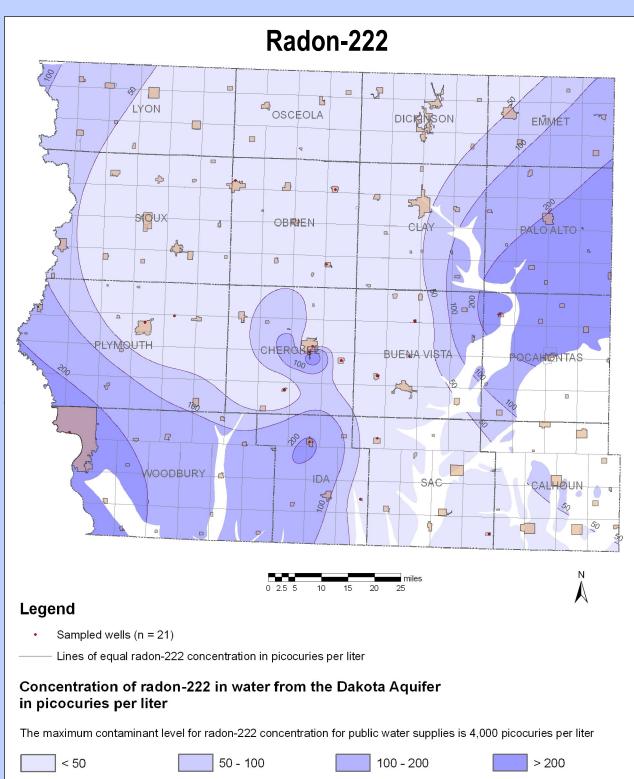
The MCL for gross beta particle levels in drinking water is based on millirems per year (4.5 mrem/yr), rather than pCi/L. A millirem is a unit of absorbed radiation dose. The risk associated with a one millirem dose is about a 1 in 8 million risk of dying of cancer, if large dose effects extrapolate linearly to zero. The loss in life expectancy from a 1 millirem dose is about 1.2 minutes. To convert a dosage exposure from a specific radionuclide measured in pCi/L, the Nuclear Regulatory Commission (www.nrc.gov/) publishes tables which provide estimates of the number of millirems harmful to various organs of the human body which will be given off by every picocurie of a variety of radioactive substances actually eaten



Concentration of gross beta particles in water from the Dakota Aquifer in picocuries per liter If the average annual gross beta particle concentration exceeds 50 picocuries per liter in a public water supply, an analysis of the sample must be performed to identify the major radioactive 10

constituents present 20 - 30 The maximum contaminant level for gross beta particle concentration for public water supplies is > 30 4 millirems per vear

Distribution of gross beta particles in water from the Dakota Aguifer in northwest Iowa. Within the area, gross beta particles were detected in seventy-two of seventy-three samples, with concentrations ranging from less than 1 to 35.5 pCi/L. None of the samples exceeded the 50 pCi/L screening level for major radioactive constituents. Currently the MCL for gross beta particles is 4 mrem/yr. Softening, anion exchange, acid neutralization and cation exchange can be used to remove gross beta particles from drinking water.



The entire state of Iowa is considered to have a predicted average indoor radon screening level of greater than 4 pCi/L (epa.gov/radon/zonemap/iowa.htm), so most homes in Iowa should be tested for

radon, and if a test shows levels greater than 4 pCi/L, a second test should be performed. Testing for radon is relatively easy and inexpensive. There are several methods to reduce radon in a home, but the one primarily used is a vent pipe system and fan, which pulls radon from beneath a house and vents it to the outside (www.epa.gov/radon001/pubs/citguide.html). Sealing foundation cracks and other openings makes this kind of system more effective and cost-efficient. If radon is entering a home through tap water, the radon can be removed from the water by aeration or carbon filtration.

Radium-226

As discussed, radium is a decay product of uranium (U) or thorium (Th). It is over one million times more radioactive than the same mass of uranium and has 25 different known isotopes. Four of these isotopes, radium-223, radium-224, radium-226 and radium-228, are found in nature, with radium-226 being the most common. Radium-226 is a product of uranium-238 decay and is formed when an alpha particle is emitted from the nucleus of a decaying thorium-230 nuclide. It is the longest-lived isotope of radium with a half-life (amount of time it takes for half of the atoms in a sample to decay) of 1,602 years. The next longest-lived isotope is radium-228, a product of thorium-232 breakdown by the emission of an alpha particle. It has a half-life of 6.7 years. Radium-226 decays by the emission of an alpha particle to radon-222, while radium-228 decays by the emission of an electron (beta particle) to actinium-228. Radium was formerly used in self-luminous paints for watches, nuclear panels, aircraft switches, clocks,

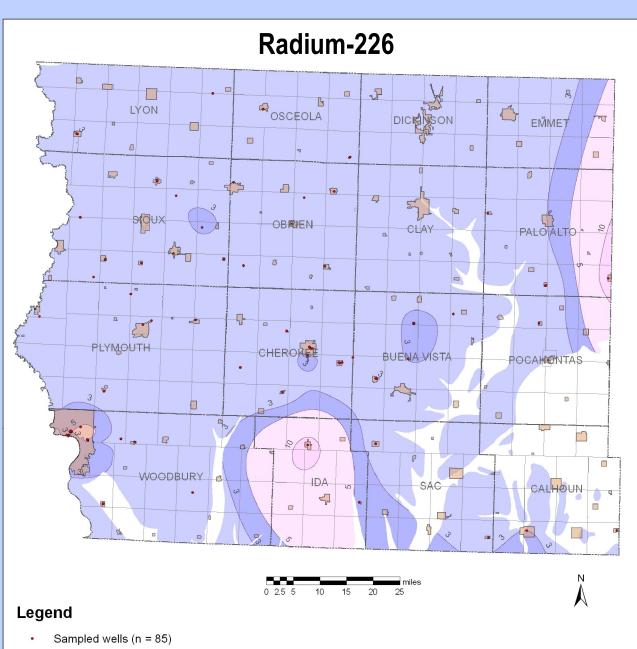
and instrument dials. Unfortunately, many watch dial painters died from the radium that had become stored in their bones. Soon after this, the adverse effects of radioactivity became widely known, although radium was still used in dials as late as the 1950s. Recently, tritium, cobalt-60 and cesium-137 have replaced radium in many applications because they are better emitters and safer to handle.

Because the human body metabolizes radium similar to the way that it metabolizes calcium, the ingestion of trace quantities of radium over time results in accumulation of radium in the skeleton. The radium that has accumulated in bone tissue decays into a series of short-lived daughter products, resulting in the emission of a number of alpha and beta particles over a short time span. As the radium and its daughter products decay, the produced energy can strip electrons from the atoms with which it collides. These electrons have a great capacity to break chemical bonds as they travel through living tissue, causing the release of additional electrons. The atoms in living tissue that lose electrons become ions at a high energy state, capable of producing chemical reactions that would not have been otherwise possible, resulting in damage to bones and other living tissue, as well as to genetic material inside the cells. The damage from continuous exposure to radium can potentially cause bone and sinus cancer.

A study conducted in the mid-1970s of radium-226 and strontium-90 in well water from the Dakota Aquifer in Iowa documented a number of statistically high radium-226 concentrations scattered throughout the aquifer (pubs.er.usgs.gov). The study also found no correlation between radium-226 and other water guality parameters in water from the aguifer. The author proposed that the anomalous radium-226 concentrations and lack of correlation with other parameters may be due to the heterogeneity of materials in the aguifer, as well as local variations in the depositional environment of the aguifer. The large number of factors determining radioactivity in groundwater make interpretation of it difficult.

The USEPA estimates that the additional lifetime risk of cancer associated with drinking water that emits alpha-particle radiation at 15 pCi/L, or has a combined concentration of radium-226 and radium-228 of 5 pCi/L, is about 1 in 10,000. This assumes consumption of 2 liters of water per day for 70 years.

For public water supplies, if the average gross alpha particle activity of quarterly samples exceeds 5 pCi/L, testing for radium-226 and radium-228 is required. If the average gross-alpha particle activity in all samples is greater than 15 pCi/L, or if the combined concentration of radium-226 and radium-228 exceeds 5 pCi/L, the water system must be monitored guarterly for an extended period. Public systems that exceed radium or gross alpha standards are required to notify consumers on a quarterly basis.



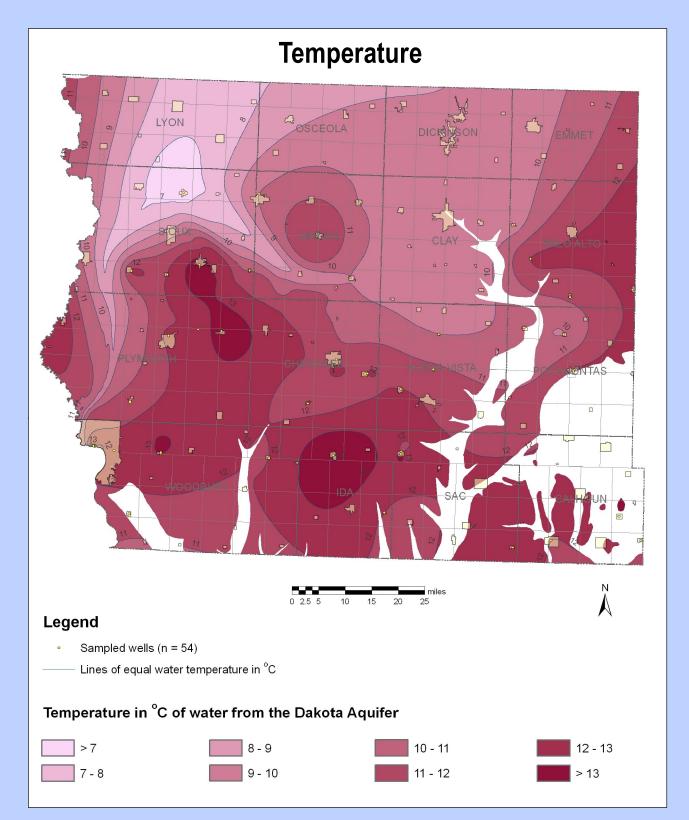
Lines of equal radium-226 concentration in picocuries per liter

Concentration of radium-226 in water from the Dakota Aquifer in picocuries per liter

< 3 Area where radium-226 concentration is less than the maximum contaminant level 3 - 5 (5 picocuries per liter for radium-226 and -228 combined) for public water supplies

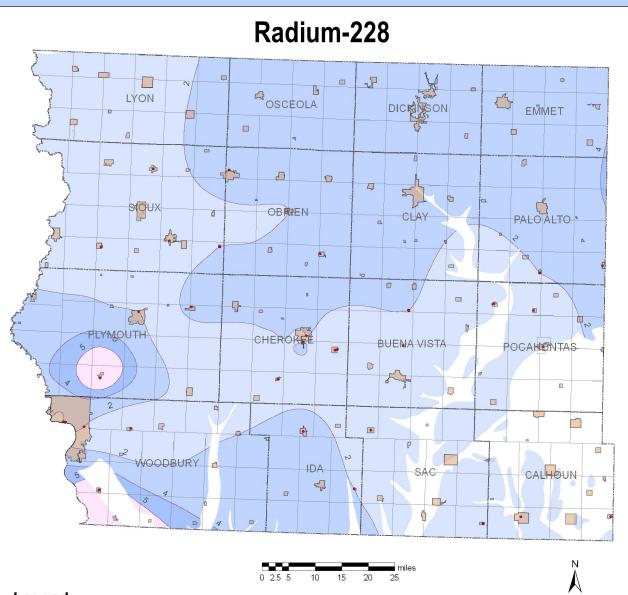
5 - 10 Area where radium-226 concentration is more than the maximum contaminant level > 10 (5 picocuries per liter for radium-226 and -228 combined) for public water supplies

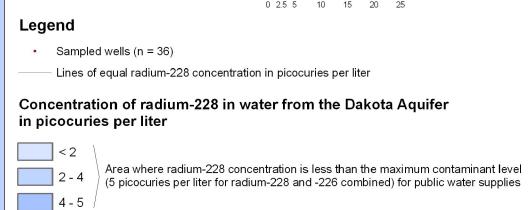
Distribution of radium-226 in water from the Dakota Aquifer in northwest Iowa. Within the study area. radium-226 was detected in 142 of the 152 samples analyzed, with concentrations ranging from 0.1 to 15.2 pCi/L. Twenty of the analyses exceeded the 5 pCi/L MCL, which includes radium-226 and radium-228 combined, while two analyses showed radium-226 concentrations equal to the MCL.



The temperature of groundwater remains relatively constant throughout the year, and depends primarily on depth. Aside from places with geothermal activity, the temperature of groundwater within a hundred feet of the land surface is about the same as a region's mean annual air temperature. In Iowa, this ranges from about 9 degrees Celsius (°C) in northern lowa to about 11 °C in southern lowa. In general, the deeper the well, the warmer the water. In the Midwest, the groundwater temperature increases about 0.8 °C for every hundred feet of depth. This rate of increase is known as the geothermal gradient. The temperature of groundwater is important for industrial users as well as for geothermal heating and cooling applications. Within the study area, temperatures range between 6 and 14°C.

particles, which readily attach to dust particles.





The chemical characteristics of groundwater are determined by factors such as the mineral content of the soil and aquifer materials through which the water passes, the rate of groundwater movement, the length of time that water remains in an aquifer, the chemistry of the water when it was trapped during sediment deposition, the chemical and physical changes that take place in aquifer materials after they are deposited and the mixing of groundwater in an aquifer with water from adjacent hydrogeologic units and/or water from the land surface.

The quality of groundwater often refers to the type and concentration of dissolved substances in the water. These substances may be naturally occurring or anthropogenic, from point or nonpoint sources, and include dissolved gases, inorganic and organic solids, and radionuclides. In addition, other particulates that might accompany water flowing from a well may be of concern. These may include sediment from the subsurface, microorganisms, and chemical precipitates that might form as a result of the disturbances brought about by the well. The concentrations of these dissolved and particulate substances are of interest because they can affect health, limit the potential uses of the water, and impact the operation of a well. One of the most common water supply considerations is whether the concentrations of constituents fall below mandated or recommended levels for drinking-water supplies.

The Dakota Aquifer is the most extensive source of large quantities of groundwater in northwest lowa. Individual sandstone beds within the aguifer range from less than 10 feet to more than 150 feet in thickness, while the cumulative thickness of the sandstone is greater than 200 feet throughout much of the western and north-central portions of study area. The aquifer is confined over most of the area by 200 to 400 feet of clay-rich glacial till as well as by thick shale, siltstone, thin chalky limestone and lignite. The confining beds underlying the aquifer include Dakota shales, undifferentiated Paleozoic rocks and Precambrian crystalline rock. The aquifer is thin or absent in the extreme northwestern and southeastern portions of the study area, and is thicker toward the west and north-central parts of the area.

Anthropogenic contaminants are usually not found in water from the Dakota Aquifer because the aquifer is protected from surface contamination in most areas by thick overlying glacial drift and shale. The most likely settings to find wells with anthropogenic contamination are areas where the aquifer is very shallow and/or not protected by relatively impermeable overlying materials. Faulty or improperly maintained well construction and distribution systems can also allow contaminated groundwater and surface water into deeper wells. As discussed, the analytical results for anthropogenic contaminants in well water in lowa are included in the Contaminant data set in the NRGIS Library (www.igsb.uiowa.edu/nrgislibx/)

Water flows through the aquifer from the north-central part of the study area to the east, south and southwest, with recharge coming from infiltration through the land surface and confining materials. Discharge from the aquifer is to the underlying Paleozoic aquifers and to the alluvium and glacial outwash deposits along the Missouri and Big Sioux rivers in the southwest part of the study area. Flow toward bedrock valleys may reflect discharge to Quaternary sand and gravel deposits in the valleys.

In much of the study area, the Dakota Aquifer contains the best quality water that is locally available, so it is widely used even though it may have aesthetic problems, such as high levels of iron, sulfate, and hardness. The water quality of the aquifer tends to be fair to poor throughout most of the study area and good to fair towards the corners of the study area. Iron and manganese are above MCLs for public water supplies in many parts of the study area. Regions of poorer water guality result from high concentrations of TDS, particularly sulfate and calcium carbonate, which are common minerals picked up by groundwater in contact with the confining layers above. The highest concentrations of these constituents occur in recharge areas with thick overlying confining units. Localities of better water quality are found where confining layers are thin, and porous pathways allow for more rapid recharge by younger, less mineralized groundwater and surface water. This occurs in the corners of the study area where the aquifer is closer to the land surface. The absence of overlying shale, along with relatively thinner glacial drift, may contribute to better water quality in localized areas in Plymouth and Cherokee counties. In general, the lower part of the Dakota has greater yield potential, but probably poorer natural water quality, than the upper part of the aquifer.

If yields from the Dakota Aquifer are significantly increased in the future, the quality of the water in the aguifer may be degraded by upward leakage from underlying Paleozoic aguifers. Large withdrawals may reverse the natural flow from the Dakota into the underlying aquifers. This may currently be occurring near the city of Le Mars, where concentrations of TDS and sulfate are abnormally high, and the potentiometric surface of the Dakota is below that of the underlying Paleozoic aguifers which contain water with higher concentrations of TDS and sulfate.

larger and better distributed data set. be reduced to acceptable levels.



Radium-228

Unlike radium-226, which poses a health hazard due to its long half-life, radium-228 poses a long-term hazard only if its parent, thorium-232, is present to provide a continuous supply of radium-228. If either isotope is swallowed in water or with food, most of it will quickly leave the body as waste, but some of it will enter the blood and be taken to all parts of the body, particularly to the bones. Small amounts of radium that are not deposited in bones will leave the body every day through waste. The inhalation risk from both isotopes is associated primarily with their decay products, radon and its short-lived daughters Radon-222 is a decay product of radium-226, while radon-220 is a decay product of radium-228. The primary health hazard associated with radon is from inhalation of its short-lived decay products, alpha

Concentration of radium-228 in water from the Dakota Aquifer

Area where radium-228 concentration is less than the maximum contaminant level

Area where radium-228 concentration is more than the maximum contaminant level (5 picocuries per liter for radium-228 and -226 combined) for public water supplies

Distribution of radium-228 in water from the Dakota Aquifer in northwest Iowa. Within the study area, radium-228 was detected in 12 of the 48 samples analyzed, with concentrations ranging from 1 to 6 pCi/L. Two of the analyses exceeded the 5 pCi/L MCL for radium-226 and radium-228 combined. Both exceedances equaled 6 pCi/L. Because of the much shorter half-life, radium-228 is much less persistent in groundwater than radium-226.



Map Sheets 3 and 4

The small set of tritium analyses suggests that near Sioux City, the aquifer is receiving rapid recharge of tritiated groundwater from the overlying alluvium, while in most parts of the study area the aquifer is being recharged by infiltration from precipitation that occurred prior to nuclear-weapons testing in the 1950s and 1960s. The small set of other radionuclide analyses show that radon-222 is found in wells in many parts of the study area, at concentrations an order of magnitude below the MCL. In addition, gross alpha activity, radium-226, radium-228, or a combination of these constituents exceed their MCLs in some areas. As discussed, the accuracy of radionuclide mapping in this report would benefit from a

Although the groundwater quality of the Dakota Aquifer is relatively poor throughout much of the study area, many communities, industries, farms and homes use it because there are no other alternatives. Domestic supplies often use the upper portion of the aquifer because drilling costs are lower, and they do not need large yields, while public and industrial users that need greater yields use the lower portion of the aguifer, even if the water guality is poorer. With treatment, contaminants that affect health can usually be reduced to meet MCLs, and contaminants that affect the aesthetic qualities of water can often