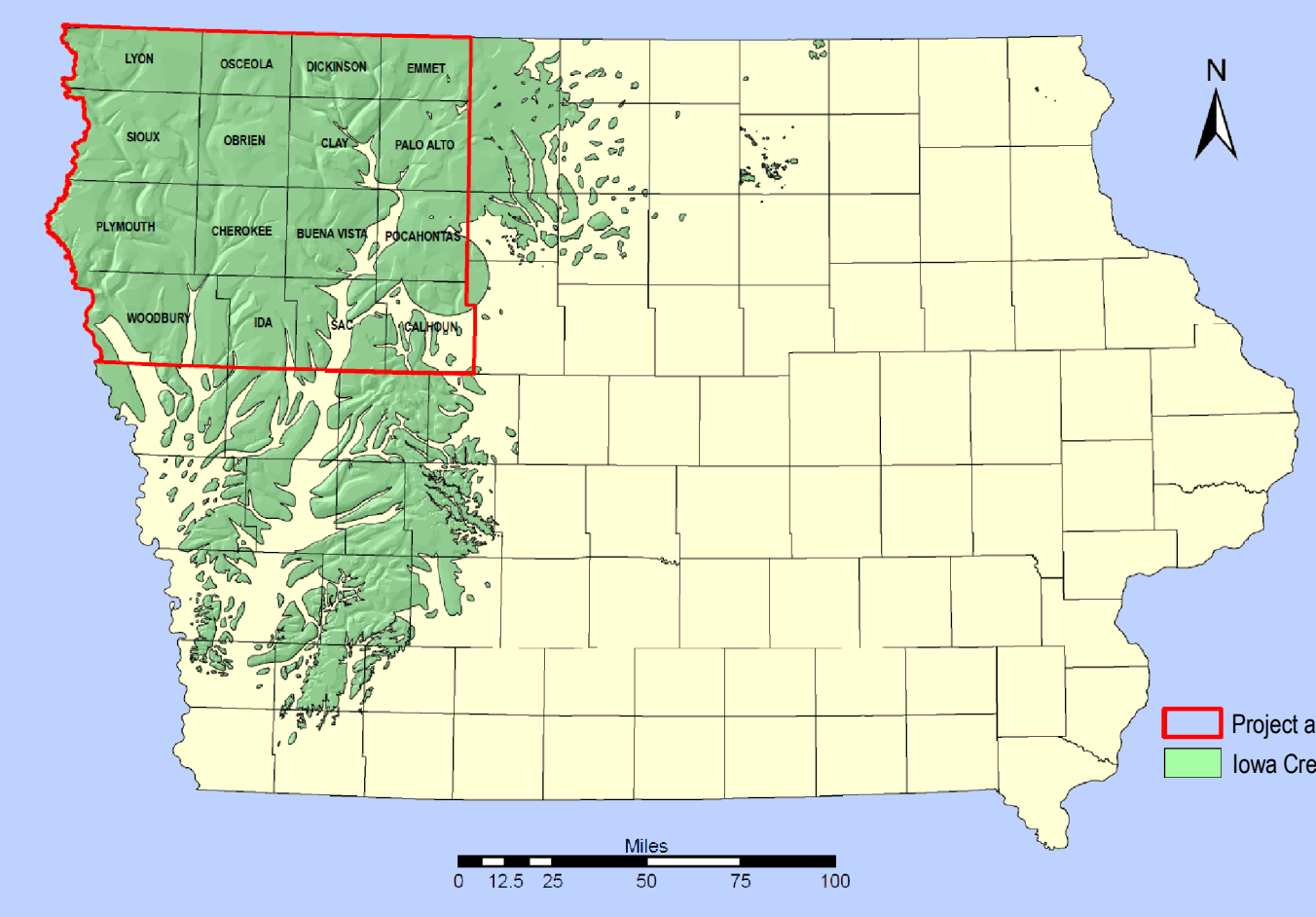


# Water Quality of the Dakota Aquifer

## The Dakota Aquifer

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

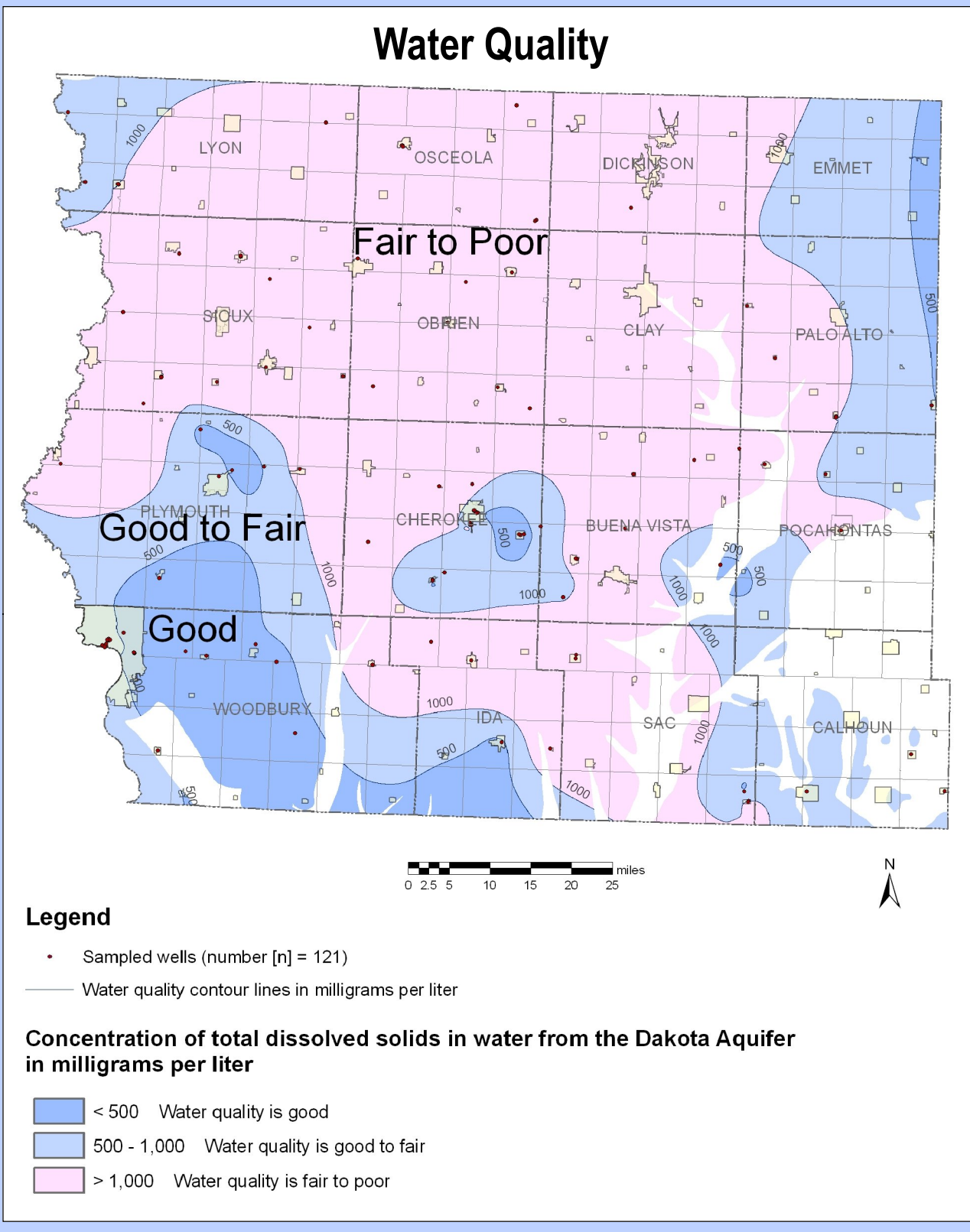


Area of occurrence and significant use of the Dakota Aquifer in western Iowa (modified from Iowa's Groundwater Basics by Jean Prior, et al., 2003, Iowa Department of Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages).

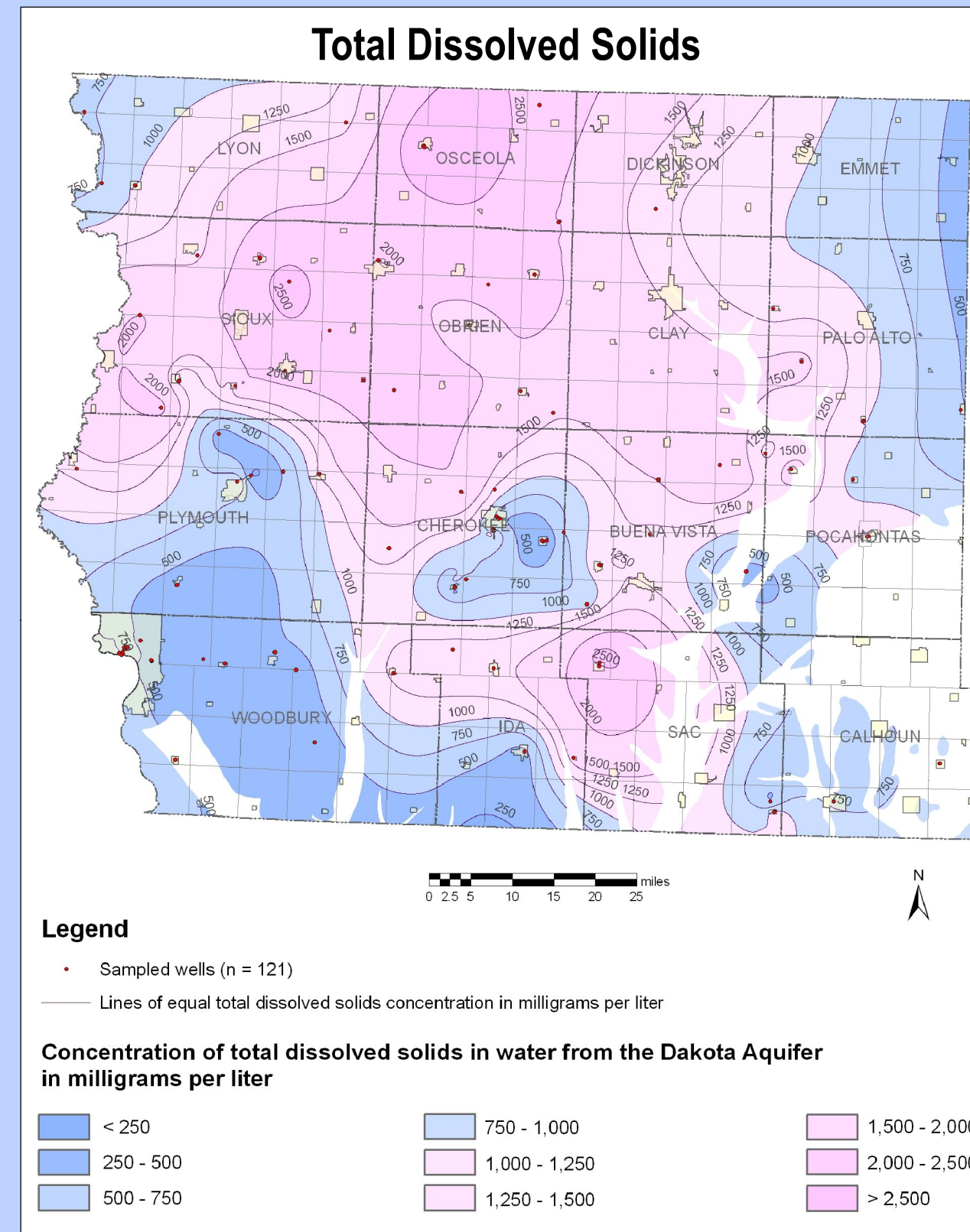
For the Dakota Aquifer groundwater quality evaluation, the upper and lower members of the aquifer were not distinguished because there is currently not enough well data to determine if there are consistent differences in water quality between them. It appears that there are differences, and that a major 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.

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 aquifer, 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 aquifer 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 aquifer 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 lignites.

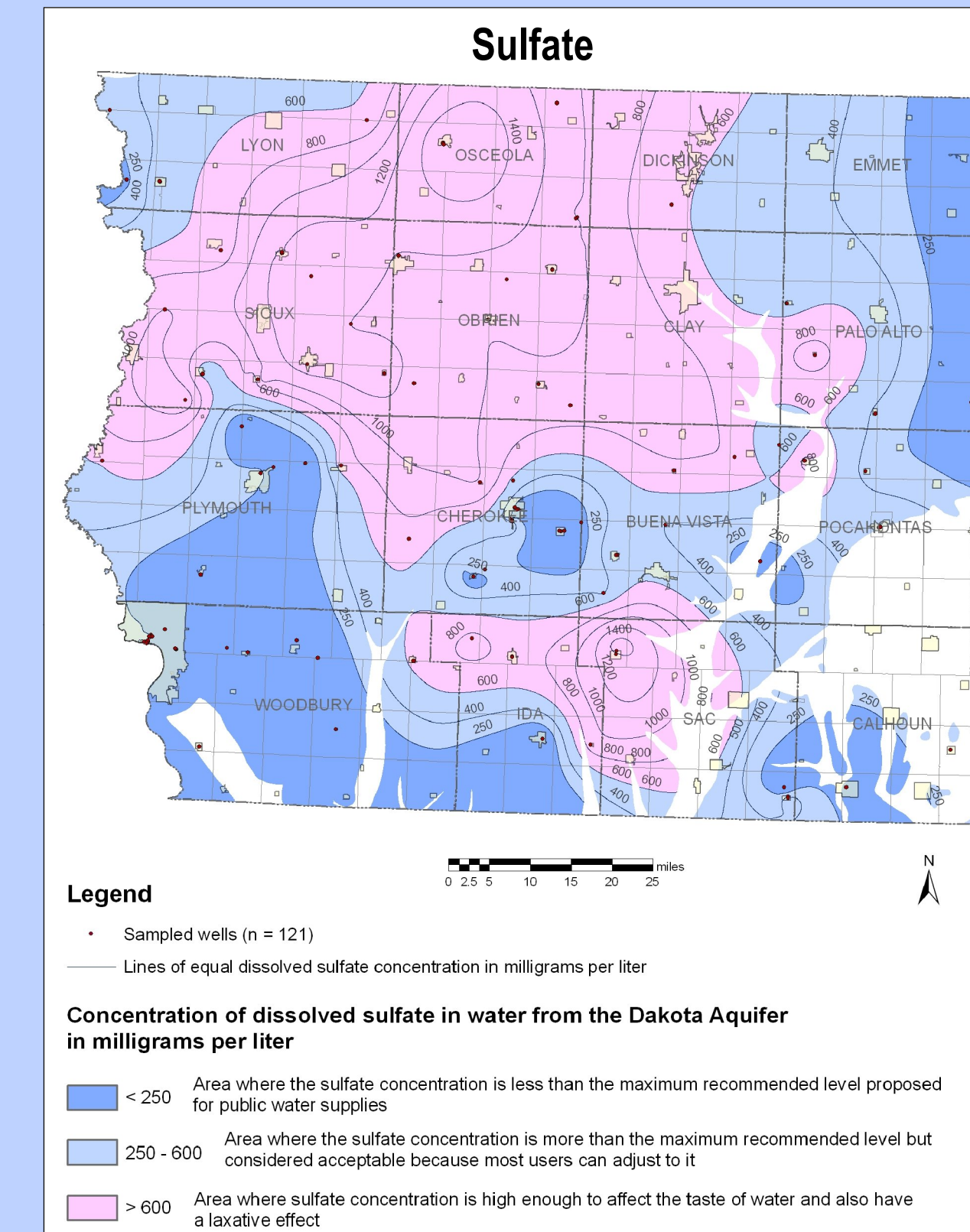
To construct the following maps, water quality analyses were averaged for each well point location. The point locations were then converted to a grid using a top to raster tool. The grid was clipped using the appropriate bedrock coverage and outline of the sixteen counties in northwest Iowa as a boundary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



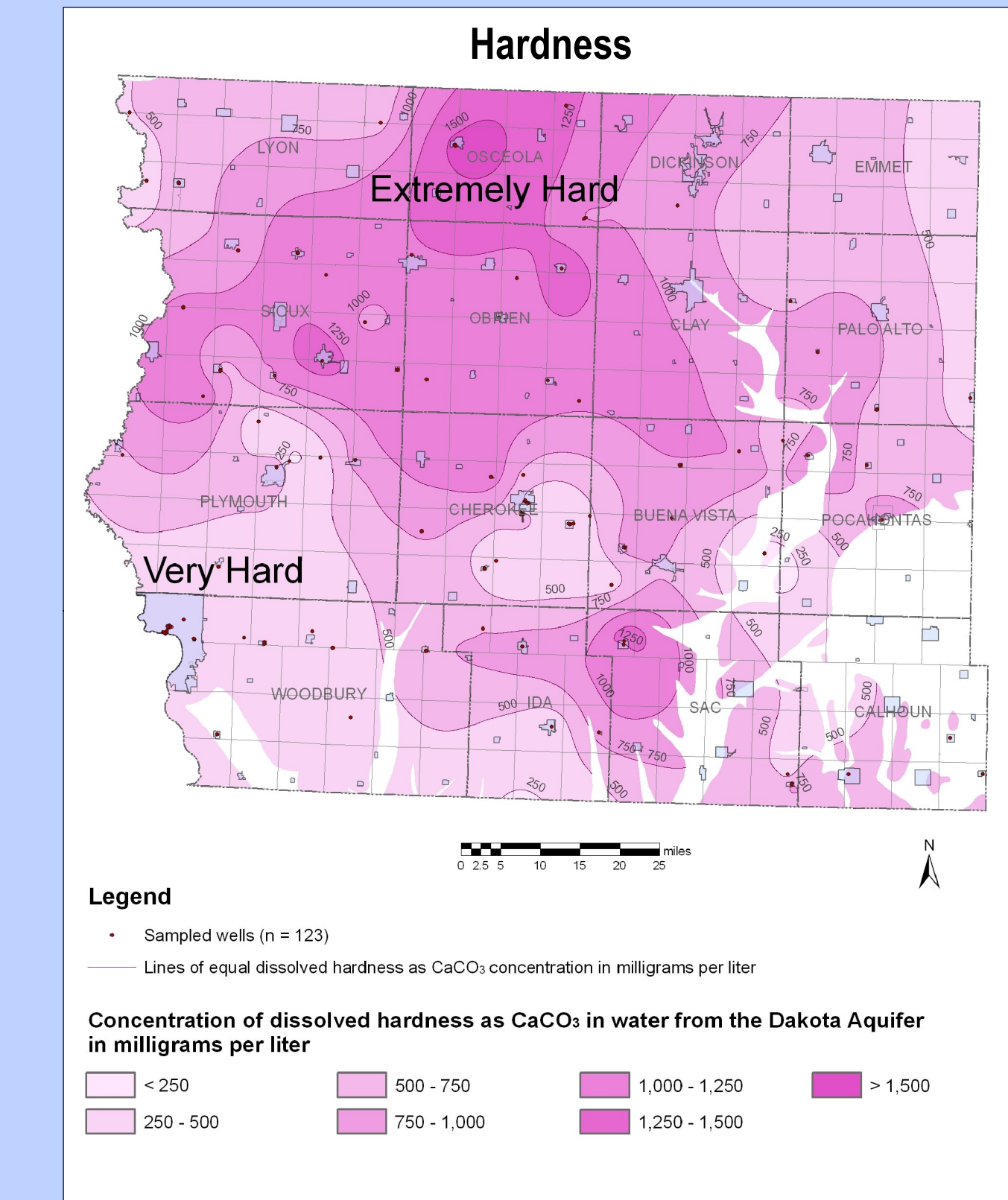
Water Quality map showing the Dakota Aquifer water quality. The map is divided into four zones: Fair to Poor (pink), Good to Fair (light blue), Good (medium blue), and Very Good (dark blue).



Total Dissolved Solids map showing the Dakota Aquifer TDS concentration. The map is divided into five zones: < 250 (light blue), 250 - 500 (medium blue), 500 - 750 (dark blue), 750 - 1,000 (light purple), and 1,000 - 1,250 (medium purple).



Sulfate map showing the Dakota Aquifer sulfate concentration. The map is divided into four zones: < 250 (light blue), 250 - 600 (medium blue), 600 - 1,000 (dark blue), and > 1,000 (purple).



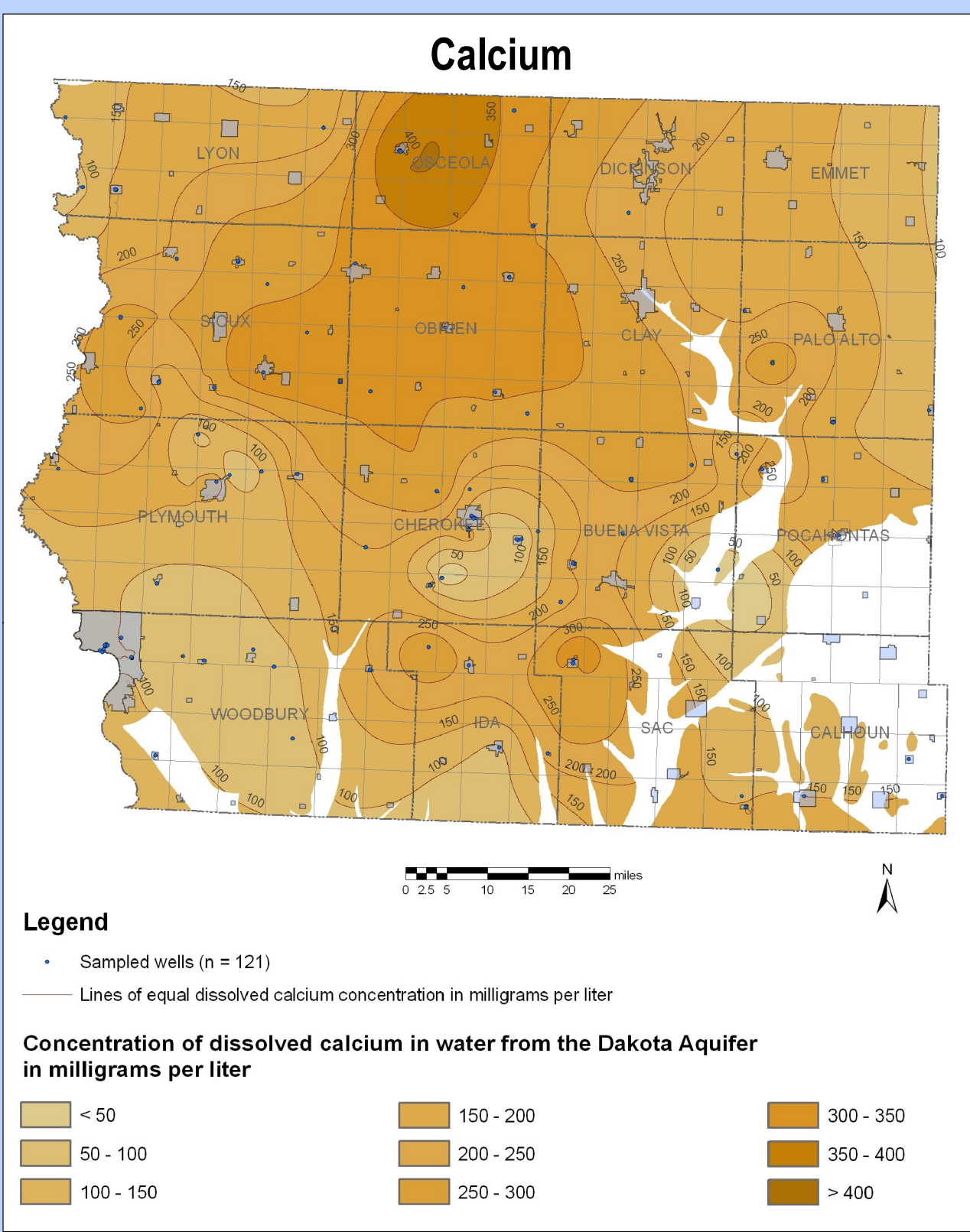
Hardness map showing the Dakota Aquifer hardness as CaCO3 concentration. The map is divided into five zones: < 250 (light blue), 250 - 500 (medium blue), 500 - 750 (dark blue), 750 - 1,000 (light purple), and 1,000 - 1,500 (medium purple).

## New Water Quality Database

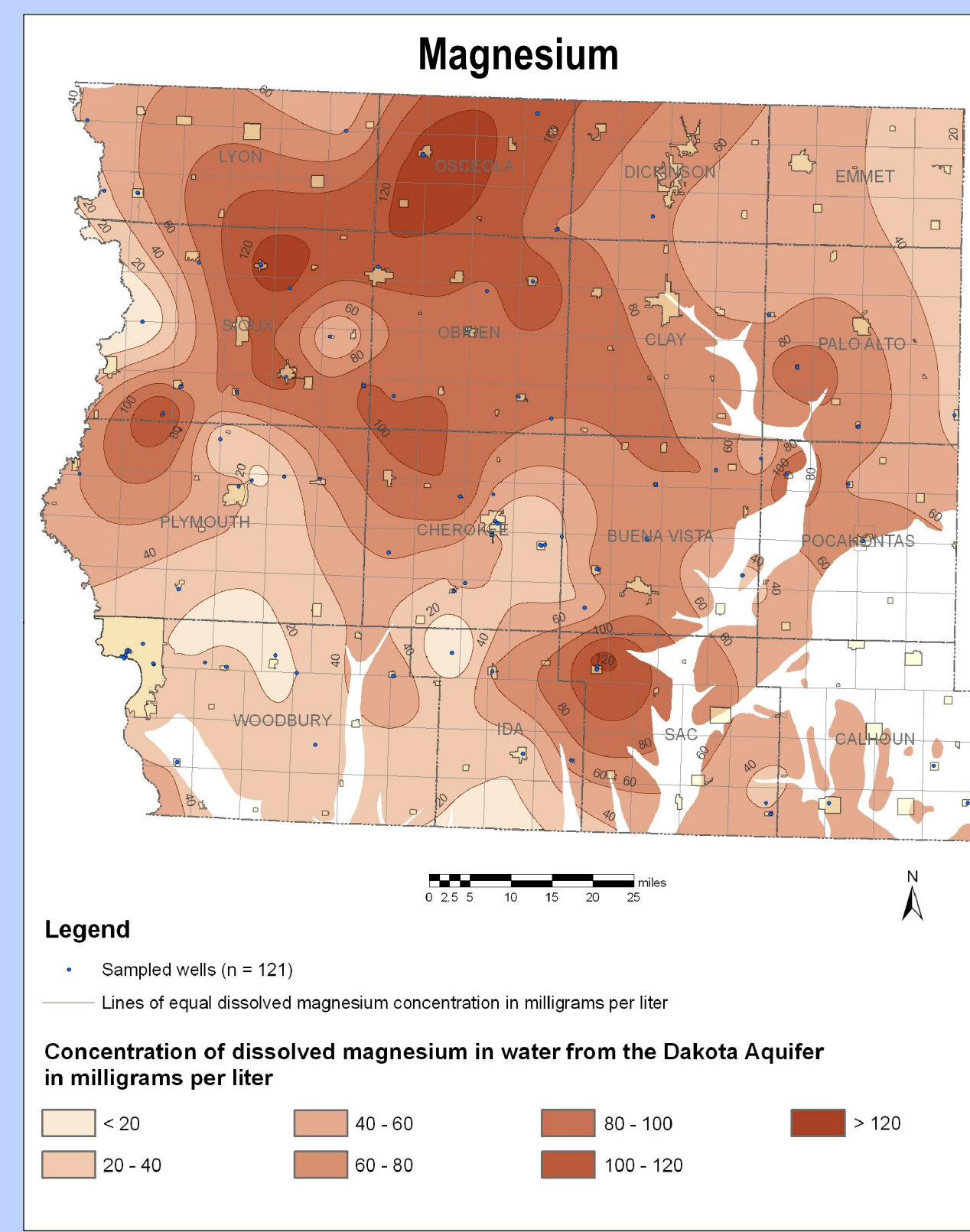
The Dakota Aquifer groundwater quality evaluation is the first water resource study to use water-quality information from a new database that is available from the Iowa Geological and Water Survey's Natural Resources Geographic Information System (NRGIS) Library ([www.igsb.uiowa.edu/nrgislib/](http://www.igsb.uiowa.edu/nrgislib/)) 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 Iowa's aquifers and determine if contamination from human activity has increased in any of the aquifers 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 Iowa. Most samples are from public water supplies and were analyzed by the University Hygienic Laboratory (UHL), but samples from a variety of projects, including aquifer and water studies, contaminant plume mapping, maximum contaminant level compliance monitoring, and analyses from other laboratories are also included in the map layers.

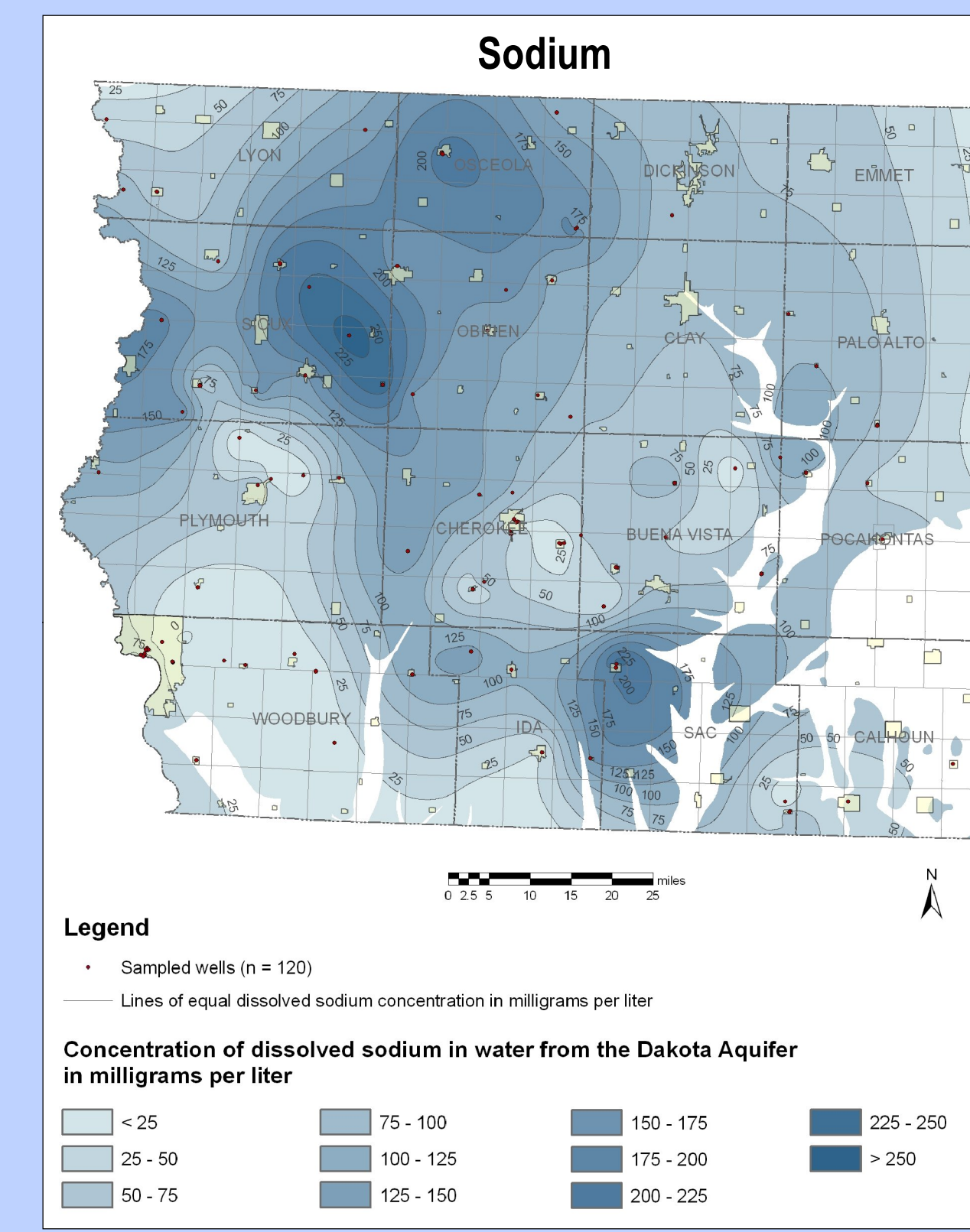
The General and Contaminant data sets each currently contain 728 different water quality analyses collected from 139 wells completed in the Dakota Aquifer within the study area in northwest Iowa.



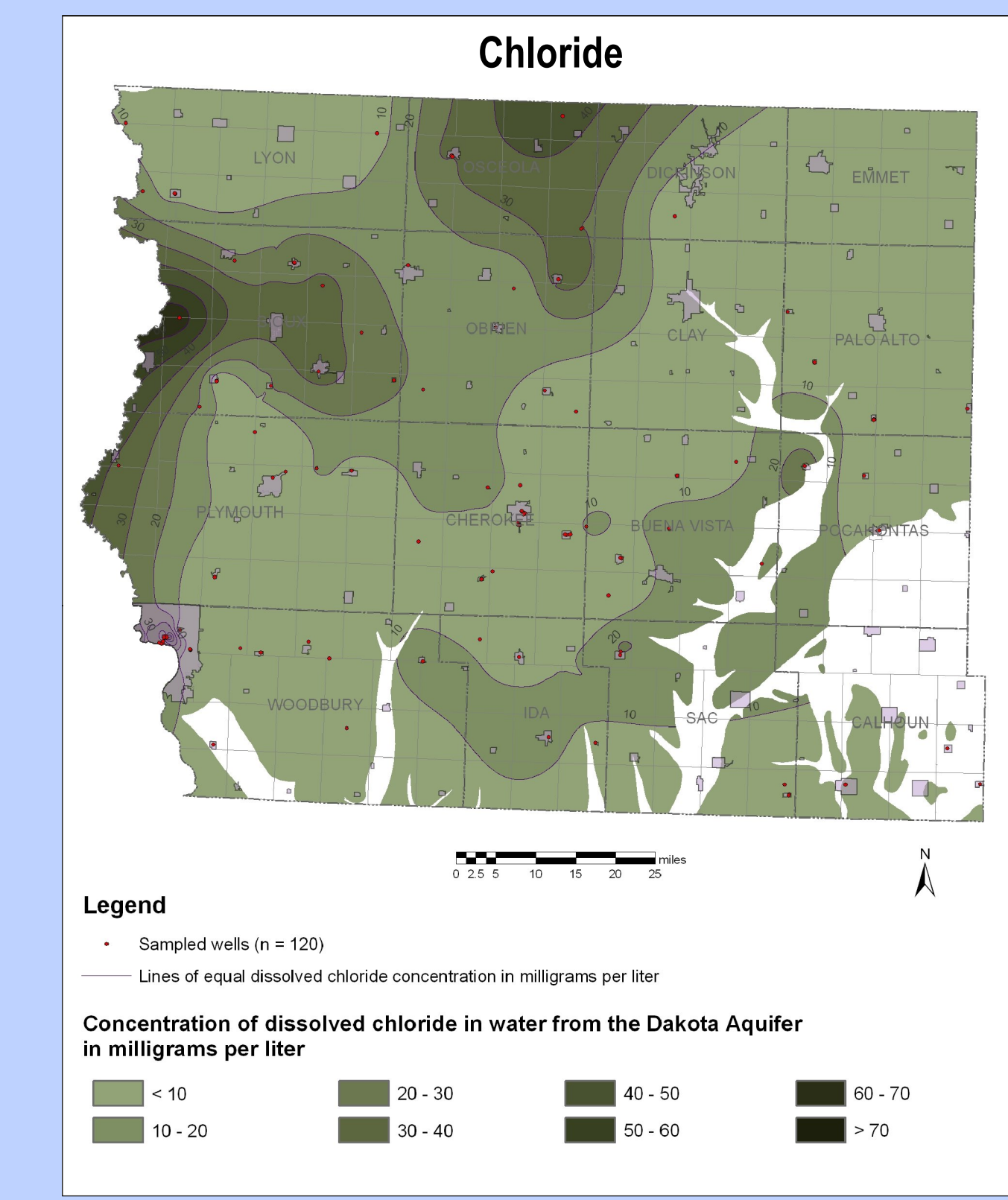
Calcium map showing the Dakota Aquifer calcium concentration. The map is divided into five zones: < 50 (light orange), 50 - 100 (medium orange), 100 - 150 (dark orange), 150 - 200 (light red), and 200 - 250 (medium red).



Magnesium map showing the Dakota Aquifer magnesium concentration. The map is divided into five zones: < 20 (light orange), 20 - 40 (medium orange), 40 - 60 (dark orange), 60 - 80 (light red), and 80 - 100 (medium red).



Sodium map showing the Dakota Aquifer sodium concentration. The map is divided into five zones: < 25 (light blue), 25 - 50 (medium blue), 50 - 75 (dark blue), 75 - 100 (light purple), and 100 - 125 (medium purple).



Chloride map showing the Dakota Aquifer chloride concentration. The map is divided into five zones: < 10 (light green), 10 - 20 (medium green), 20 - 30 (dark green), 30 - 40 (light purple), and 40 - 50 (medium purple).

## 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 (HCO<sub>3</sub>) to groundwater. Sulfur-bearing minerals like gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O) and pyrite (FeS<sub>2</sub>), while less common, add sulfate (SO<sub>4</sub>) 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 (H<sub>2</sub>S), ammonia (NH<sub>3</sub>), methane (CH<sub>4</sub>), 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 Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages).

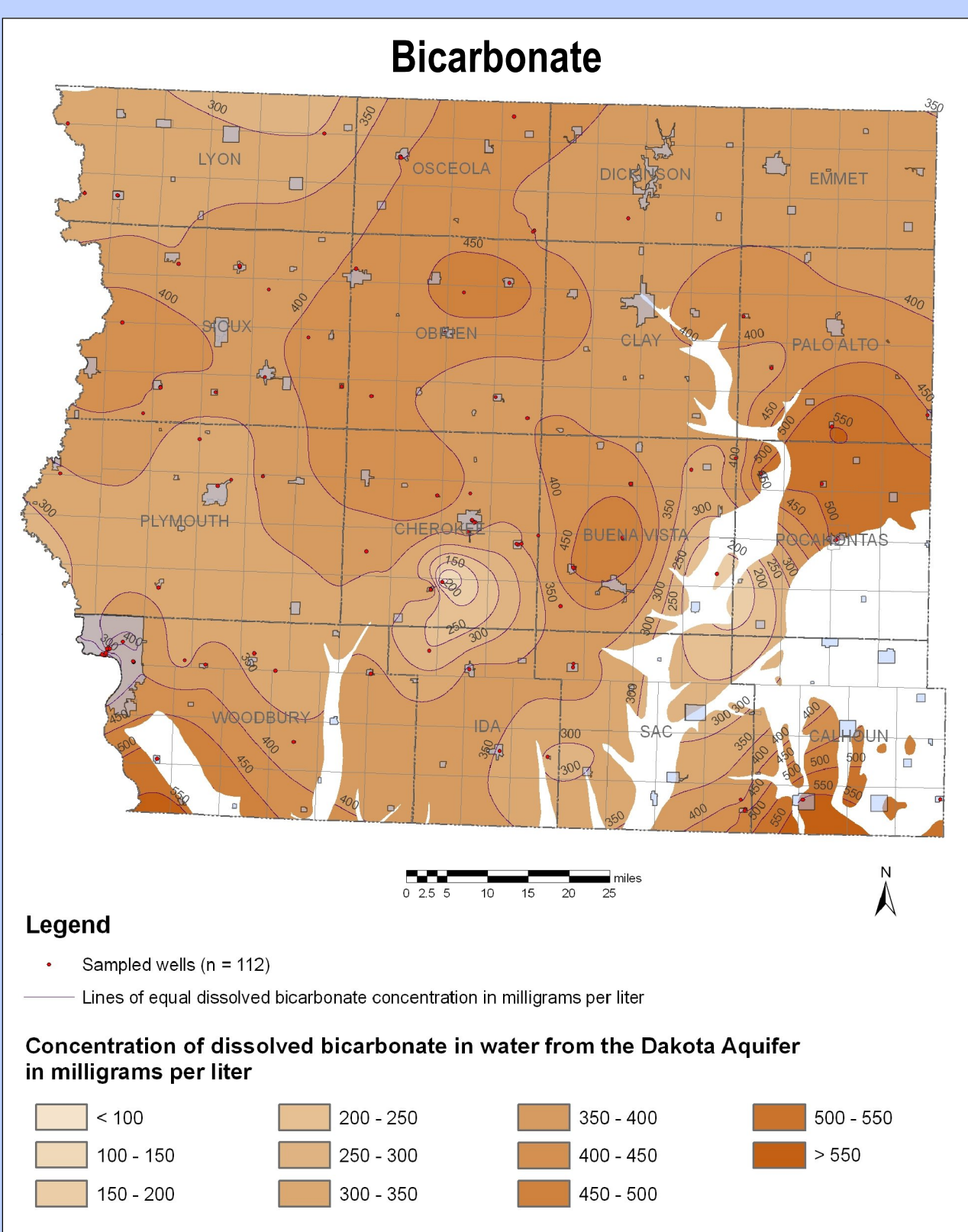
Constituent or Property	Maximum contaminant level (MCL) for public water supplies	Recommended maximum level	Constituent naturally occurring	Comments
<b>Microorganisms</b>	No bacteria in 95% of samples collected		•	Indicates pathway for potentially harmful microorganisms; inadequate well condition; possibly faulty well construction
<b>Inorganic chemicals</b>				
Arsenic (As)	0.01 mg/L		•	Can cause adverse health effects; carcinogenic
Chloride (Cl)		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 <sub>3</sub>			•	Limits lathering ability of soap; causes scale buildup; water becomes objectionable for domestic use when >100 mg/L
Calcium (Ca) and Magnesium (Mg)			•	Objectionable taste; stains laundry and porcelain
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 <sub>3</sub>	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 foaming in boilers; consult physician if on a low sodium diet
Sulfate (SO <sub>4</sub> )		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
<b>Suspended sediment</b>			•	Gives water a muddy or turbid appearance; causes pump wear
<b>Dissolved gases</b>				
Hydrogen sulfide (H <sub>2</sub> S)			•	Causes rotten egg odor; corrosion of pipes, casing and pumps
Methane (CH <sub>4</sub> )			•	Explosive, flammable
<b>Common ions</b>				
Bicarbonate (HCO <sub>3</sub> )			•	Contributes to the alkalinity of water; principal ion in fresh water
Carbonate (CO <sub>3</sub> )			•	Contributes to the alkalinity of water; seldom present in fresh water
<b>Radionuclides</b>				
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
<b>Organic chemicals</b>				
Pesticides	Arazox 0.003 mg/L Atrachlor 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
<b>Temperature</b>			•	Affects the desirability and economy of water use for cooling
<b>pH</b>	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
<b>Specific conductance</b>		1,600 µmhos/cm	•	Capability to carry electrical current or content of dissolved minerals
mg/L = milligrams per liter; equivalent to parts per million		µmhos/cm = micromhos per centimeter		

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

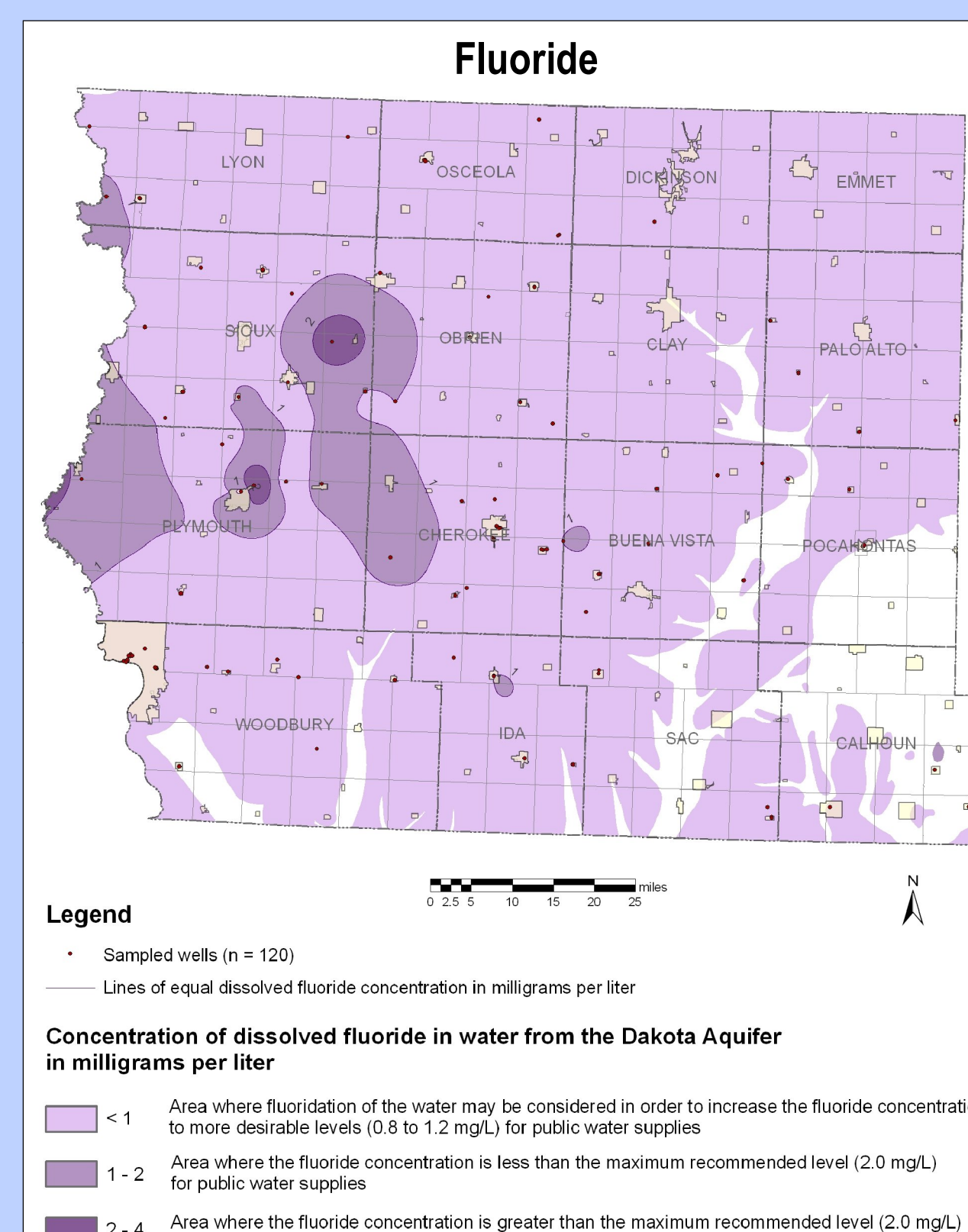
The preceding table summarizes some commonly occurring chemical constituents and properties that can cause problems in Iowa's drinking water. Contaminants that affect health must meet legally enforceable primary Maximum Contaminant Level (MCL) standards for public water supplies, while contaminants that 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 (NO<sub>3</sub>), 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.

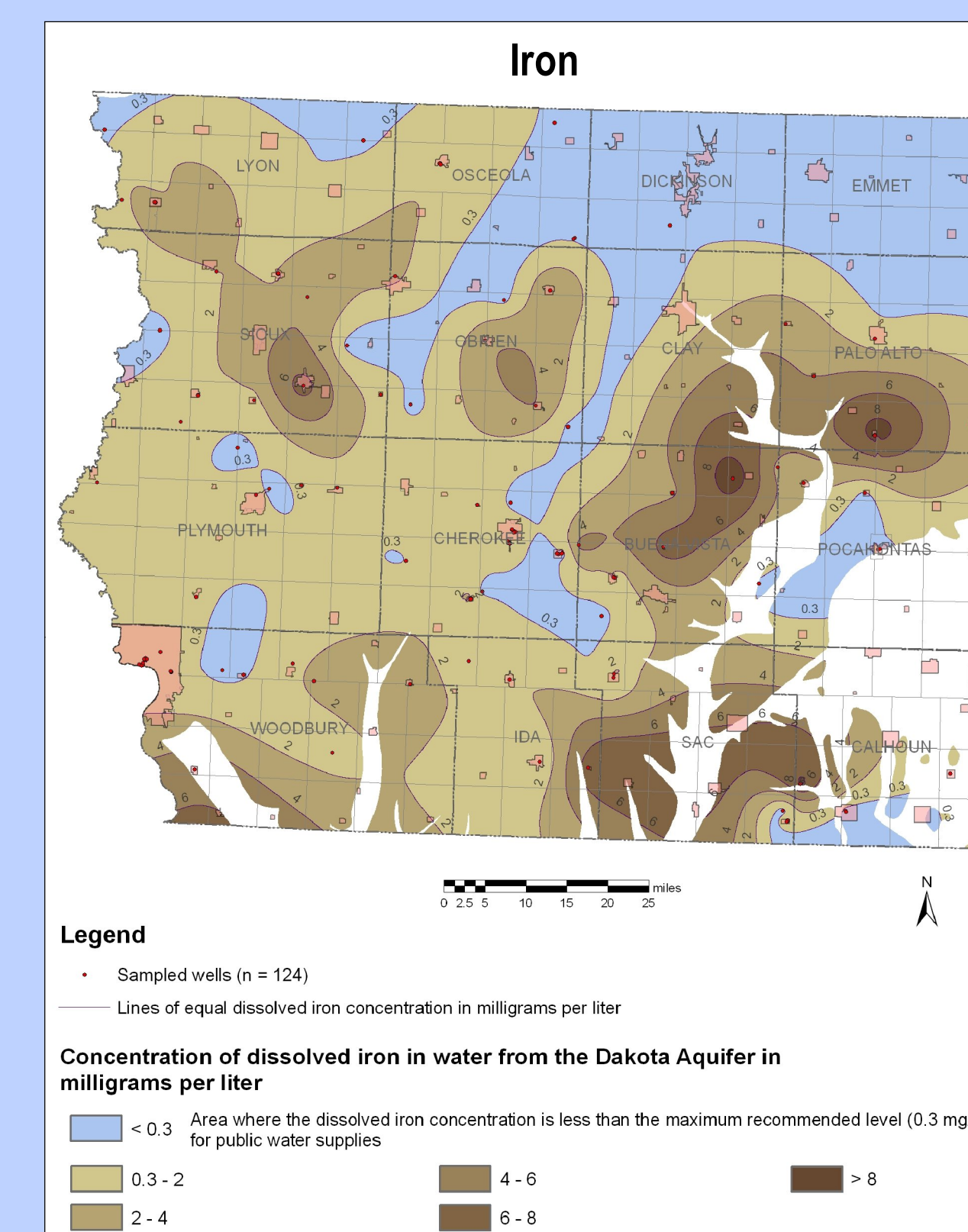
Publications about water quality and its effects on health are available from the U.S. Environmental Protection Agency (USEPA) at [www.epa.gov/safewater/](http://www.epa.gov/safewater/), the U.S. Geological Survey (USGS) at [www.water.usgs.gov/](http://www.water.usgs.gov/), and the Iowa Geological and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



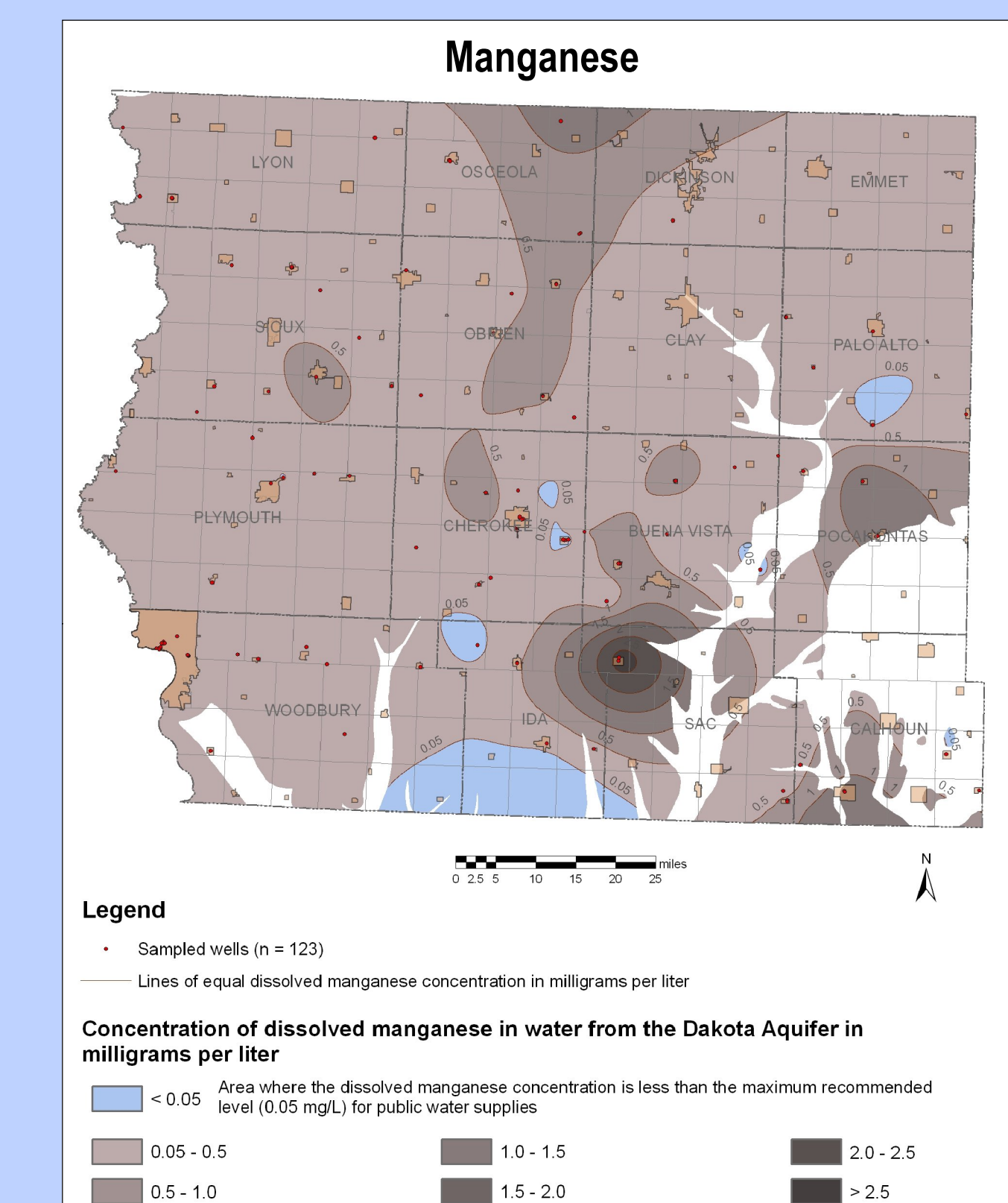
Bicarbonate map showing the Dakota Aquifer bicarbonate concentration. The map is divided into five zones: < 100 (light orange), 100 - 150 (medium orange), 150 - 200 (dark orange), 200 - 250 (light red), and 250 - 300 (medium red).



Fluoride map showing the Dakota Aquifer fluoride concentration. The map is divided into five zones: < 0.1 (light purple), 0.1 - 0.2 (medium purple), 0.2 - 0.3 (dark purple), 0.3 - 0.4 (light blue), and 0.4 - 0.5 (medium blue).



Iron map showing the Dakota Aquifer iron concentration. The map is divided into five zones: < 0.3 (light blue), 0.3 - 0.4 (medium blue), 0.4 - 0.5 (dark blue), 0.5 - 0.6 (light purple), and 0.6 - 0.7 (medium purple).



Manganese map showing the Dakota Aquifer manganese concentration. The map is divided into five zones: < 0.05 (light green), 0.05 - 0.1 (medium green), 0.1 - 0.15 (dark green), 0.15 - 0.2 (light purple), and 0.2 - 0.25 (medium purple).

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.

The predominant source of magnesium in groundwater is dolomite, which is a sedimentary rock similar to limestone. Dolomite differs from limestone, CaCO<sub>3</sub>, by the addition of magnesium to make the formula, CaMg(CO<sub>3</sub>)<sub>2</sub>. Magnesium and calcium can be removed from water by softening. There is currently no MCL or SMCL for magnesium for public water supplies.

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.

Excessive levels of sodium and chloride in water can cause salty tastes and corrosion of piping and fixtures. Currently there is no MCL for chloride, but there is a 250 mg/L SMCL based on objectionable taste. Reverse osmosis will reduce chloride by 90 to 95% and sodium by 94 to 98%. Electrodialysis and distillation are also effective in reducing the chloride and sodium content of water. In addition, a strong base anion exchanger, which is the later portion of a two-column deionizer, does an excellent job at removing chloride from water for industrial applications.

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.

Fluoride is a common constituent of many minerals like fluorapatite 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, ion exchange, and distillation. Adsorption by calcium phosphate, magnesium hydroxide, 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.

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.

Manganese occurs in many soils and sediments as well as in rocks whose structures have been changed by heat and pressure. Reducing manganese concentrations with treatment is difficult because of the complex ways it can form with other constituents in water. The concentration of manganese in water is affected by oxidation state, pH, bicarbonate-carbonate-OH ratios, and the presence of other minerals, particularly iron. In low concentrations, iron and manganese are not hazardous to health, but are considered secondary or aesthetic contaminants. Concentrations of iron and manganese greater than their SMCLs may cause staining of clothing and plumbing fixtures and can also produce an unpleasant odor and taste. Iron and manganese can be reduced in drinking water by polyphosphate treatment, ion exchange, filtration and chlorination. Within the study area, manganese concentrations are above the 0.05 mg/L SMCL for public water supplies everywhere except for a few localized areas.

