



Arsenic in Nebraska's Groundwater and Public Water Supplies

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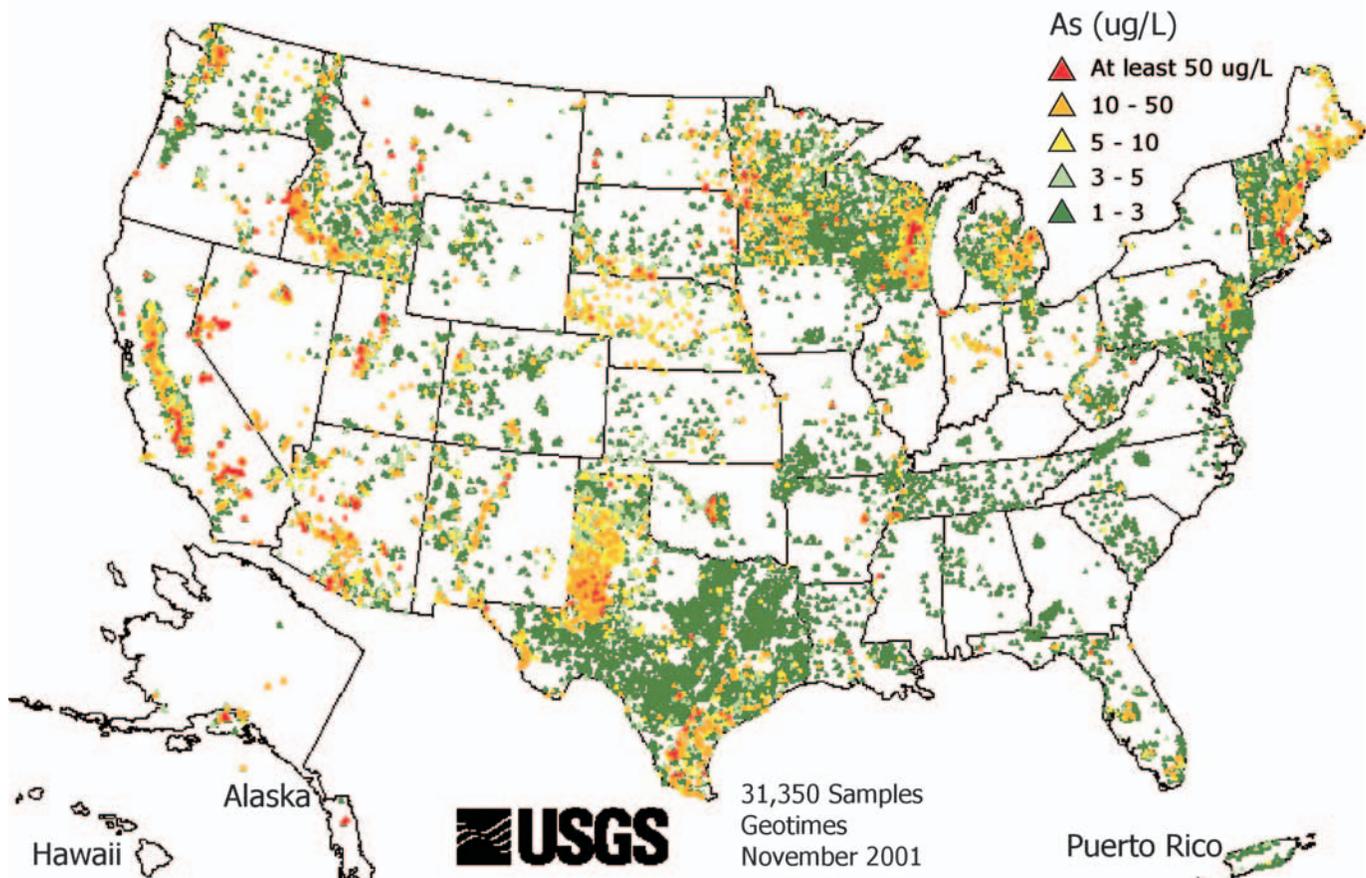
Introduction

Because arsenic (As) in drinking water is considered a primary contributor to cancer in humans, the U.S. Environmental Protection Agency (EPA) recently lowered the maximum contaminant level (MCL) for arsenic from 50 micrograms per liter ($\mu\text{g/L}$) to 10 $\mu\text{g/L}$ (1 $\mu\text{g/L}$ = 1 part per billion: ppb). This MCL will become effective in 2006. On a national scale, EPA has estimated that of the 74,000 public water supply systems regulated by this MCL, approximately 4,000 systems will have to make changes to comply with it. Of the affected systems, 97 percent are small systems that serve fewer than 10,000 people each. The average increase in household cost for water that meets the new MCL depends on the size of the water system and how many people it serves. For small community water systems (serving fewer than 10,000 people), the increase in annual household cost is expected to range between \$38 and \$327.

For community water systems that serve more than 10,000 people, annual household costs for water are expected to increase from \$0.86 to \$32.

There have been a number of national and regional evaluations of the occurrence of arsenic in groundwater and drinking water within the United States (fig. 1a and 1b). These data suggest a complicated distribution pattern for arsenic. Arsenic concentrations greater than 10 $\mu\text{g/L}$ are apparently more common in the western United States than in the eastern part (fig. 1a). Detailed investigations in several states suggest that arsenic concentrations exceed 10 $\mu\text{g/L}$ more often than previously thought. Data for Nebraska indicate arsenic concentrations are expected to be greater than 5 $\mu\text{g/L}$ in at least 25 percent of groundwater samples in the majority of counties (fig. 1b). Although these relatively large-scale evaluations provide valuable information, they do not provide sufficient informa-

Fig. 1a. Arsenic concentrations from wells across the United States. Modified from Ryker (2001) and Welch and others (2000).



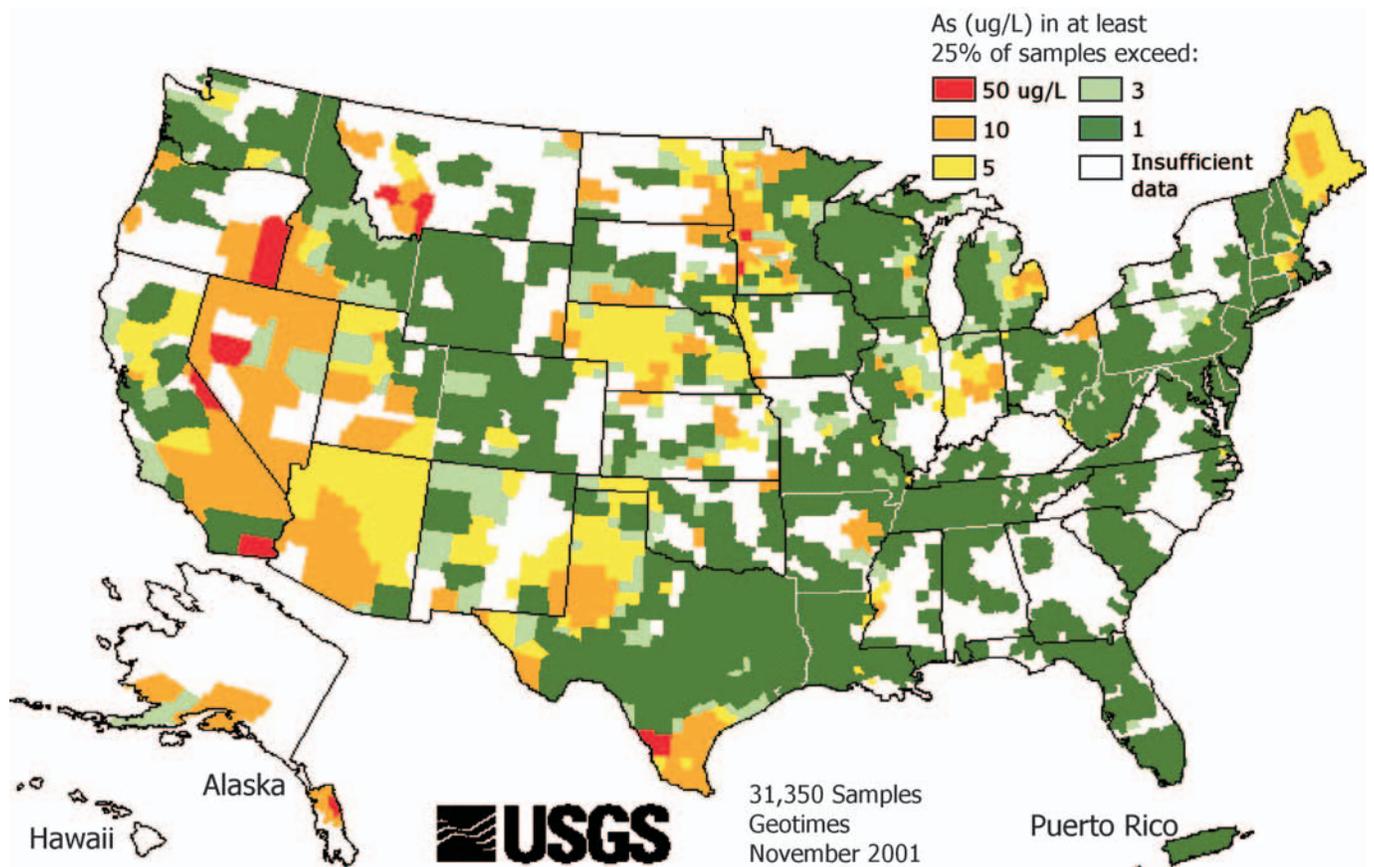


Fig. 1b. Counties where at least 25 percent of the groundwater samples will have arsenic concentrations above a specified level. Modified from Ryker (2001) and Welch and others (2000).

tion to address water-quality management concerns at the local level, where regulations are going to be applied.

Lowering the MCL to 10 $\mu\text{g/L}$ will have significant implications for public water systems in Nebraska. According to the Nebraska Health and Human Services System, 75 public water systems will have arsenic concentrations above the 10 $\mu\text{g/L}$ MCL (fig. 2). These water systems serve nearly 100,000 people. Of the affected public water systems, 73, or 97 percent, serve less than 10,000 people. Meeting the new standard is estimated to cost these water systems about \$120 million.

There are many important questions about the management of water resources used by public water systems with respect to arsenic in Nebraska. These include, but are not limited to:

- Where and how much arsenic is in the groundwater?
- Why does arsenic occur where it does?
- In what chemical form does the arsenic occur?
- What can we do about arsenic in a well?

The primary purpose of this fact sheet is to provide background information about our current understanding of the distribution of arsenic in Nebraska's groundwater. A better understanding of arsenic in the state's groundwater can help water resource managers minimize public health risks by avoiding water with high arsenic concentrations and help reduce the cost of new regulations related to arsenic on public water systems.

Arsenic in the Environment

Arsenic, a naturally occurring element, is found throughout the environment. For most people, food is the major source of exposure. Arsenic ranks 20th in natural abundance among elements in the Earth's crust. Most of the more than 200 minerals in which arsenic occurs as a major constituent are relatively rare and occur in mineralized areas where they are ore minerals or alteration products. There are only a few minerals that are important in groundwater environments. One of these is pyrite (FeS_2). Because of their similar chemical behavior, arsenic substitutes for sulfur in the crystal structure of many sulfide minerals, of which pyrite is the most common. Pyrite is formed under reducing, or low-oxygen, and low-temperature conditions and is found in sediments of many aquifers. When pyrite is exposed to oxidizing conditions, it breaks down to form iron-oxide minerals, and associated trace constituents such as arsenic are released. Arsenic concentrations can also be significant in iron oxides and hydrous iron oxides, either as part of the mineral structure or sorbed (taken up and held) to the mineral surface.

Arsenic chemistry is very complex because it has many forms. In groundwater systems, arsenic generally is present as arsenate (As^{5+}) or arsenite (As^{3+}). Arsenite is the most damaging to human health and is about an order of magnitude (10 times) more potent than arsenate in breaking down human chromosomes, which may contribute to cancer. Arsenite is also apparently more difficult to remove from drinking water than arsenate.

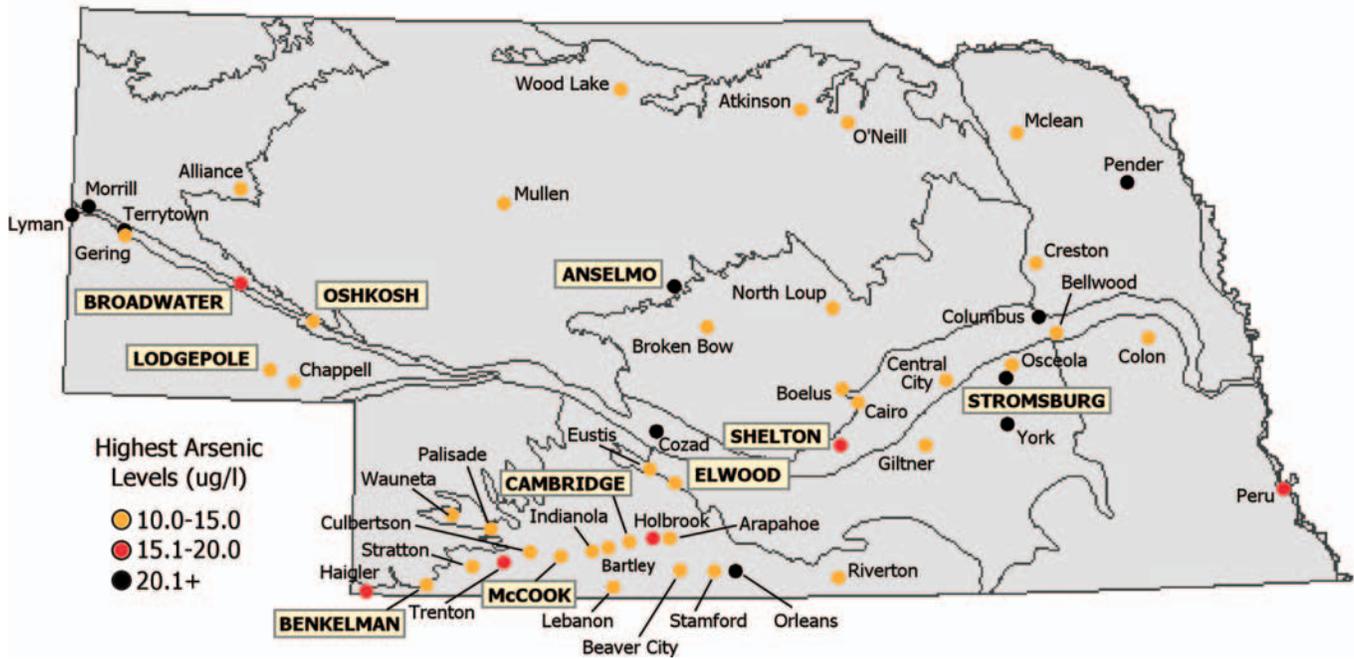


Fig. 2. The 75 towns that have historic arsenic levels greater than 10 µg/L and could be out of compliance when the new arsenic rule goes into effect in 2006. The public water supply systems in this study are highlighted with boxes.

Studies have linked long-term exposure to arsenic in drinking water to cancer of the bladder, lungs, skin, kidney, liver, and prostate. Acute (short-term) high-level inhalation exposure to arsenic dust or fumes has resulted in gastrointestinal problems (nausea, diarrhea, abdominal pain). Chronic (long-term) inhalation exposure to arsenic in humans is associated with irritation of the skin and mucous membranes. Non-cancer effects of ingesting arsenic include cardiovascular, pulmonary, immunological, neurological effects and endocrine problems such as diabetes. The current MCL for arsenic of 50 µg/L was set by EPA in 1975, based on a Public Health Service standard originally established in 1942. A March 1999 report by the National Academy of Sciences concluded that this standard did not achieve EPA's goal of protecting public health and recommended that the MCL be lowered as soon as possible. On June 22, 2000, EPA proposed a new drinking water standard of 5 µg/L for arsenic and requested comment on options of 3 µg/L, 10 µg/L and 20 µg/L. EPA evaluated over 6,500 pages of comments from about 1,100 individuals. Under 1996 amendments to the Safe Drinking Water Act, EPA issued the 10 µg/L MCL as its final rule on June 22, 2001. Currently, the proposed drinking water guidelines do not consider the relative toxicity of the different arsenic "species" such as As⁵⁺ versus As³⁺. However, an understanding of both the arsenic concentration and its speciation (array of forms) would be beneficial to any groundwater management program for public water systems interested in mitigating the impact of arsenic in the water supply.

Arsenic in Nebraska Groundwater

The distribution of arsenic in groundwater and its sampling within Nebraska are shown on figure 3a-c. Thirteen groundwater regions are plotted on figure 3c. Groundwater regions are determined by similar landscape characteristics and

conditions of geologic occurrence of groundwater. Boundaries between regions represent zones of gradual change. Data have been compiled from the National Water Information System of the U.S. Geological Survey (USGS, <http://waterdata.usgs.gov/>) and the National Uranium Resource Evaluation program of the National Geochemical Data Base (NURE, http://geology.cr.usgs.gov/pub/open-file-reports/ofr-97-0492/state/nure_ne.htm). Both of these data sets are maintained by the USGS. These data have been collected from wells used for public water supplies, research, agriculture, industry and domestic water supplies. Figure 3a shows the 395 sample locations in the USGS data base.



Lynne Klawer, project coordinator, monitors pH and temperature of water flushed from a main in Stromsburg, Neb., prior to arsenic sampling. IANR photo by Brett Hampton.

Table 1. Summary of arsenic data by groundwater region and geologic unit from which water is obtained. S = sand; G = gravel; Grp. = Group; Fm. = Formation; NCG Fms. = Niobrara, Carlisle and Greenhorn formations.

Region	Data Source: USGS				Data Source: NURE			
	Geologic Units	Ave.	Range	No. of Samples	Geologic Units	Ave.	Range	No. of Samples
1	All	7	<1-18	75	All	4.7	<0.5-69.4	427
	Quaternary S and G	7.1	<1-16	28	Quaternary S and G	4.4	1.9-11.4	8
	Tertiary Ogallala Grp.	7.0	1-18	46	Quaternary Dune Sand	4.3	<0.5-69.4	220
	Tertiary White River Grp.	8.0		1	Tertiary Ogallala Grp.	4.9	<0.5-17.3	186
					Tertiary Arikaree Grp.	7.1	3.6-10.4	8
2	All	5.4	<1-59	210	All	3.2	<0.5-32	255
	Quaternary S and G	5.0	<1-24	207	Quaternary S and G	2.6	<0.5-32	179
	Tertiary White River Grp.	31.7	9-59	3	Tertiary Ogallala Grp.	4.4	<0.5-9.1	34
					Tertiary White River Grp.	5.1	1.5-9.8	17
					Cretaceous Pierre Shale	3.9	0.6-8.1	11
					Cretaceous NCG Fms.	3.6	<0.5-8.1	14
3	All	4.8	1-13	8	All	2.0	<0.5-10.9	21
	Quaternary S and G	5.8	1-13	6	Quaternary S and G	2.9	<0.5-10.9	13
	Dakota Fm.	2.0		1	Dakota Fm.	<0.5		1
	Pennsylvanian Limestones/Shales	1.0		1	Pennsylvanian Limestones/Shales	0.7	<0.5-1.5	7
4	All	3.3	<1-11	85	All	2.1	<0.5-13	456
	Quaternary S and G	3.2	<1-11	84	Quaternary S and G	2.1	<0.5-13	424
	Tertiary Ogallala Grp.	10		1	Tertiary Ogallala Grp.	1.8	0.5-4	26
					Cretaceous NCG Fms.	1.9	0.8-2.1	6
5	All	11.4	5-39	9	All	6.6		1
	Tertiary Ogallala Grp.		All samples		Tertiary Ogallala Grp.		All samples	
6	All	5.1	<1-11	28	All	5.1	<0.5-23.4	353
	Quaternary S and G	5.6	3-11	10	Quaternary S and G	5.4	2-9.4	17
	Tertiary Ogallala Grp.	4.7	1-8	3	Tertiary Ogallala Grp.	5.7	<0.5-16.1	123
	Tertiary Arikaree Grp.	5.0	4-7	10	Tertiary Arikaree Grp.	4.2	<0.5-22.7	155
	Tertiary White River Grp.	4.3	0.5-11	5	Tertiary White River Grp.	6.0	1.7-23.4	58
7	All	7.3	2-18	31	All	7.3	<0.5-85	349
	Quaternary S and G	7.0	4-12	7	Quaternary S and G	8.4	3.1-15.4	7
	Tertiary Ogallala Grp.	5.5	3-8	8	Tertiary Ogallala Grp.	5.5	<0.5-19.7	219
	Tertiary White River Grp.	9.4	4-18	12	Tertiary Arikaree Grp.	11.4	<0.5-55.6	10
	Cretaceous (Fox Hills/Lance)	5.3	2-9	4	Tertiary White River Grp.	<0.5-1	3-85	113
8	All	6.3	1-17	20	All	3.3	<0.5-17.8	544
	Quaternary S and G	6.1	2-12	9	Quaternary S and G	3.2	<0.5-17.8	107
	Tertiary Ogallala Grp.	6.5	1-17	11	Tertiary Ogallala Grp.	3.3	<0.5-16.9	426
					Cretaceous Pierre Shale	2.3		1
					Cretaceous NCG Fms.	4.7	<0.5-13.2	10
9	All	8.7	3-14	12	All	2.9	<0.5-10.5	211
	Quaternary S and G	9.3	3-14	9	Quaternary S and G	2.9	<0.5-10.5	93
	Tertiary Ogallala Grp.	6.7	5-10	3	Tertiary Ogallala Grp.	3.2	0.6-5.4	81
					Cretaceous Pierre Shale	4.1	3.8-4.4	2
					Cretaceous NCG Fms.	2.2	0.8-6.8	35
10	All	1.7	<1-5	19	All	1.4	<0.5-10	213
	Quaternary S and G	1.7	0.5-5	9	Quaternary S and G	1.5	<0.5-10	130
	Dakota Fm.	1.7	<1-5	10	Tertiary Ogallala Grp.	3.0	1.9-4.2	4
					Cretaceous NCG Fms.	2.5	0.6-5.4	23
					Dakota Fm.	0.8	<0.5-5.5	49
				Pennsylvanian Limestones/ Shales	0.8	<0.5-2.1	7	

Table 1 (cont). Summary of arsenic data by groundwater region and geologic unit from which water is obtained.

Region	Data Source: USGS				Data Source: NURE			
	Geologic Units	As Concentrations (µ/L)		No. of Samples	Geologic Units	As Concentrations (µ/L)		No. of Samples
		Ave.	Range			Ave.	Range	
11	All	2.7	<1-12	31	All	1.2	<0.5-11.1	473
	Quaternary S and G	2.7	1-9	21	Quaternary S and G	1.4	<0.5-11.1	340
	Dakota Fm.	1.9	0.5-4	5	Cretaceous NCG Fms.	0.9	<0.5-1.5	3
	Permian Limestones/Shales	3.8	0.5-12	5	Dakota Fm.	1.2	<0.5-6.2	104
					Permian Limestones/Shales	1.4	<0.5-3.5	8
				Pennsylvanian Limestones/Shales	0.8	<0.5-2.8	18	
12	All	3.5	1-7	6	No NURE samples here			
	Quaternary S and G	5.0	2-7	3				
	Tertiary Ogallala Grp.	3.5	2-5	2				
	Dakota Fm.	1		1				
13	No USGS samples here				All	7.5	<0.5-64	93
					Quaternary S and G	6.9	<0.5-18.6	7
					Tertiary Arikaree Grp.	2.9	0.6-5.2	19
					Tertiary White River Grp.	10.5	0.5-64	37
					Cretaceous Pierre Shale	6.7	<0.5-44	27
					Cretaceous NCG Fms.	6.4	<0.5-9.6	3

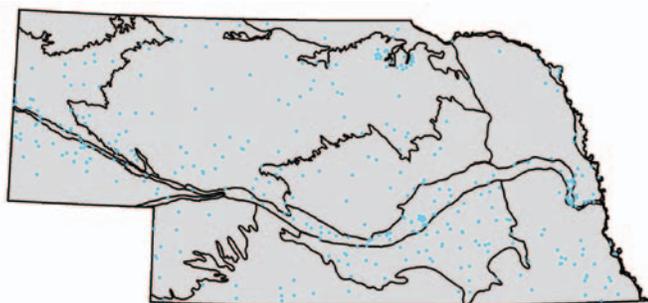


Fig. 3a. Locations of U. S. Geological Survey (USGS) samples for which arsenic was analyzed.

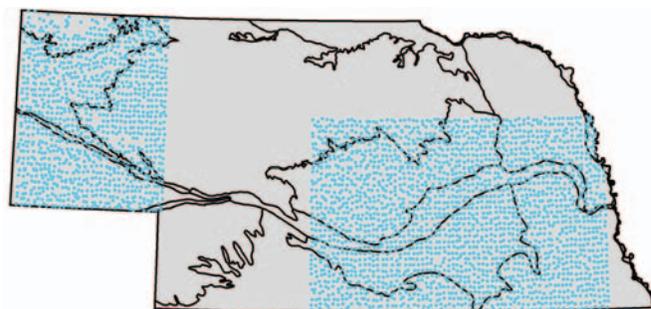


Fig. 3b. Locations of National Uranium Resource Evaluation (NURE) samples for which arsenic was analyzed.

Figure 3b shows the sample locations for the 3,391 sample locations in the NURE data base. Figure 3c shows the spatial distribution of samples from both data sets that have arsenic concentrations greater than 5 µg/L. It also provides the average arsenic concentration, the range of arsenic concentrations and number of samples in each groundwater region for which arsenic data are available.

Figure 3c indicates that the highest arsenic concentrations are found in the Nebraska Panhandle and the western Sand Hills. Arsenic concentrations greater than 15 µg/L are most common in groundwater regions 6, 7, and 13, where the average concentrations are 5.1 and 7.3 µg/L in the USGS data base and 7.5 µg/L in the NURE data base, respectively. Average arsenic concentrations generally decrease to the east, where the lowest average concentrations of 1.4 and 1.2 µg/L are in groundwater regions 10 and 11, respectively, in the USGS data base.

Table 1 provides a summary of the data for each groundwater region by geologic unit. The predominant groundwater-bearing units in groundwater regions 6, 7 and 13, where the average concentrations are the highest, include alluvial (river-deposited) Quaternary-age sand and gravel deposits that over-

lie the Tertiary-age Ogallala, Arikaree, and/or White River groups. Water that has been apparently derived from the Arikaree and White River groups generally has the highest individual, highest average, and greatest range of values for arsenic concentrations. These geologic units contain a significant amount of fine-grained volcanoclastic rocks (that is, material derived from volcanic activity). This type of geologic material is commonly associated with relatively high concentrations of arsenic.

The USGS and NURE data clearly document distinct spatial and geologic variability on a regional scale that makes the prediction of arsenic concentrations very difficult. The wide range of arsenic values within and among the same geologic unit reflects the complex behavior of arsenic in groundwater systems, which is strongly influenced by the geologic and chemical environments within which the water moves. A characteristic feature of areas having high arsenic concentrations is that there is a substantial degree of spatial variability in the distribution of arsenic. This results in a limited ability to predict the concentration of arsenic in a particular well from the results of analyses from neighboring wells. This means that there is really no better alternative than to analyze individual wells for

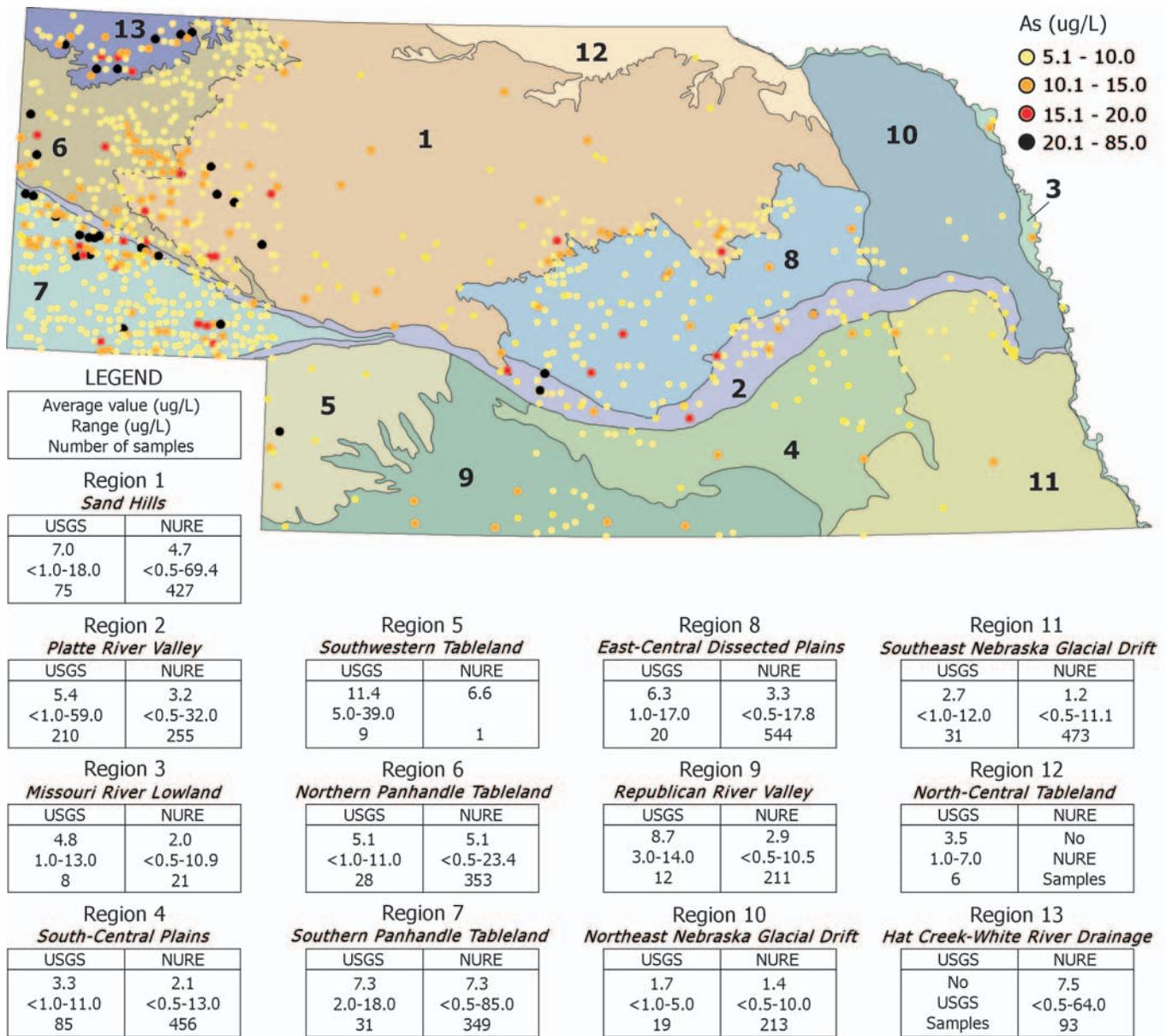


Fig. 3c. Locations where arsenic concentrations are greater than 5 µg/L. Data were mapped in the context of Nebraska's 13 groundwater regions. The table associated with each region lists the average arsenic concentration, range and the number of samples from each data base.

their arsenic concentrations. Finding a new source of water is, at best, a trial-and-error process. However, assessing historical data from sources such as NURE and USGS can provide some guidance for well drillers that may improve the likelihood of finding a new water source with lower arsenic concentrations.

Arsenic in Nebraska's Public Water Supplies

In October 2002, we began an investigation to improve our understanding of the behavior of arsenic in selected Nebraska public water supplies. Our long-term goal is to use our understanding to assist water resource managers in minimizing public health risks related to high arsenic concentrations (> 10 µg/L) in groundwater and potentially contribute to reducing the cost of new regulations related to arsenic in public water supplies.

Our project has focused on the occurrence and variability of arsenic in two wells from each of the following public water systems: Benkelmen, Cambridge, McCook, Stromsburg, Shelton, Elwood, Lodgepole, Broadwater, Oshkosh, and Anselmo. Figure 4 shows the location of the participating public water supplies. Table 2 summarizes the geologic and arsenic data for the individual wells.

Similar to the USGS and NURE data, our public water systems data, shown in figure 4, document spatial variability on a local scale. Average arsenic concentrations in wells from the same public water system and similar geologic units can be virtually the same (for example, McCook) or can have arsenic concentrations in one well that are as much as 60 percent higher than another (for example, Anselmo). This variability makes the prediction of arsenic concentrations very difficult. In figure

Table 2. Characteristics and summary of arsenic data for public water supply study sites. Med. = medium; gr. = grained.

Town	Well	Depth (m)	Geologic Description From Driller's Log	Number of Samples	Arsenic Concentration in $\mu\text{g/L}$, Average (Range)
Anselmo	641	52	Gravel, fine- to coarse-gr. sand	13	11.9 (11.0-13.1)
	871	53	Fine-gr. gravel, coarse-gr. sand and sandstone	11	19.1 (17.5-20.7)
Benkelman	961	15	Fine- to med.-gr. gravel and coarse gravel	13	10.7 (9.3-12.0)
	962	16	Fine-gr. sand to coarse-gr. gravel with shale fragments	13	9.8 (8.9-11.1)
Broadwater	551	19	No geologic log. Sand and gravel inferred from well 551 log and elevation.	10	15.5 (13.4-17.9)
	751	26	Sand, fine- to med.-gr. gravel and Brule clay	12	12.5 (11.3-13.6)
Cambridge	531	19	Sand, gravel, clay, with shale fragments and calcium carbonate concretions	13	12.7 (11.3-14.0)
	831	19	Coarse-gr. sand and gravel	13	9.4 (8.6-10.6)
Elwood	71	102	Sand and gravel	13	5.5 (5.0-6.9)
	881	109	Sand and gravel	13	6.3 (5.7-8.1)
Lodgepole	641	30	Brule clay (White River Group)	13	7.2 (6.6-8.1)
	751	61	Brule clay (White River Group)	13	9.8 (9.0-10.5)
McCook	4	25	Fine- to coarse-gr. sand and gravel	13	10.9 (9.4-12.6)
	6	23	Coarse-gr. sand and gravel	13	11.5 (10.4-12.8)
Oshkosh	1451	15	Sand and gravel	13	12.7 (11.0-13.5)
	1741	23	Sand and gravel	13	9.3 (8.4-10.9)
Shelton	49	18	Sand and gravel, green gravel	13	4.2 (3.8-4.8)
	97	61	Sand, gravel, and clay	13	10.0 (9.3-10.7)
Stromsburg	1	63	Fine- to coarse-gr. sand, gravel, and blue clay	13	22.1 (19.5-26.0)
	3	55	Coarse-gr. sand and fine-gr. gravel	13	19.8 (16.2-23.3)

4, arsenic concentrations varied by as little as 1.5 $\mu\text{g/L}$ to as much as 7 $\mu\text{g/L}$ in individual wells over the one-year study. In some cases, the apparent variation in arsenic concentrations brings the well into compliance with the MCL. There is no recognizable seasonal variation in arsenic concentrations at any of these sites. The general absence of long-term temporal variability suggests that the collection of one sample per year for most of the wells in this study will adequately characterize the arsenic concentration to which the population drinking this water will be exposed. However, this conclusion could only be obtained by actually sampling these wells over time. Considering that variations in arsenic concentrations are a possibility, it is suggested that public water supplies characterize the variability of arsenic over time in their wells to assess the

extent to which one yearly sample will adequately characterize arsenic in their water supplies.

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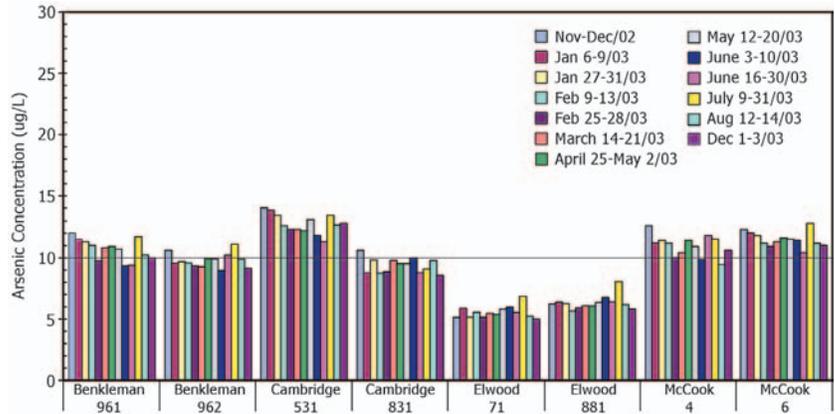


Fig. 4a. Arsenic concentrations obtained from public water supplies in the Republican River valley and associated uplands. The numbers associated with each town are the local well identifiers. The line at 10 µg/L is the MCL.

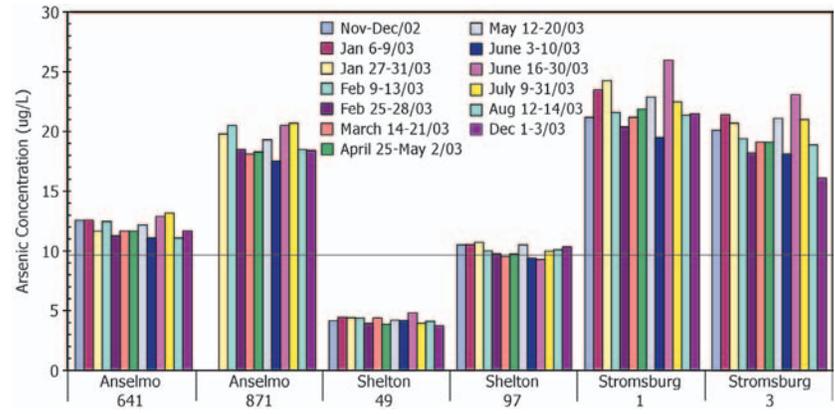


Fig. 4b. Arsenic concentrations obtained from public water supplies in central Nebraska. The numbers associated with each town are the local well identifiers. The line at 10 µg/L is the MCL.

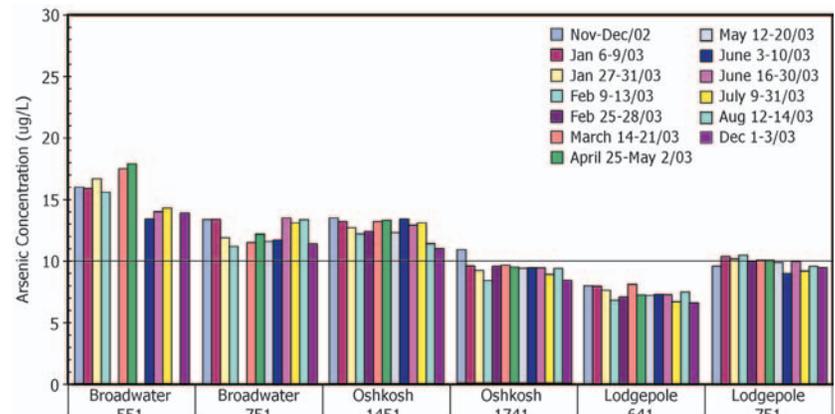


Fig. 4c. Arsenic concentrations obtained from public water supplies in the Nebraska Panhandle. The numbers associated with each town are the local well identifiers. The line at 10 µg/L is the MCL.



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