Significance of private water supply wells in a rural Nevada area as a route of exposure to aqueous arsenic

Mark Walker, Marnee Benson and W. Douglass Shaw

ABSTRACT

In many rural areas domestic drinking water needs are met by a mixture of public water supplies and private water supplies. Private supplies are not subject to the regulations and management requirements of the Safe Drinking Water Act (SDWA). Amendments to the SDWA recently lowered the standard for arsenic from 50 to 10 ppb in public water supplies (effective in 2006).

Churchill County, Nevada, has approximately 25,000 residents. Slightly more than half (13,500) rely on private domestic wells for water supply. Ample data and media publicity about high arsenic concentrations in water supplies and a federally led investigation of a leukaemia cluster suggested that residents of the county would be aware that arsenic concentrations in private wells were highly likely to exceed the 10 ppb standard.

A survey carried out in 2002 showed that a majority of respondents (72%) consumed water from private wells and among them a minority (38%) applied treatment. Maximum, median and minimum concentrations of arsenic from all samples ($n = 351$) were 2,100, 26 and <3 ppb, respectively. Seventy-four per cent of all samples exceeded 10 ppb. A majority (87%) of those who applied treatment consumed tap water. The relatively low rate of application of treatment suggested that these rural residents did not recognize that consumption could have associated health risks. However, those who applied treatment were $\sim$0.3 times as likely to be consuming water with $>$ 10 ppb arsenic than those who consumed water that was not treated.

In areas where concentrations of arsenic have been demonstrated to be high, it may be important to conduct a focused educational effort for private well owners to ensure that they take the steps needed to assess and reduce risks associated with contaminants found in tap water, including arsenic. An educational effort could include promoting sampling efforts to determine the magnitude of arsenic concentrations, explaining the risk associated with arsenic consumption and providing information about choices for home treatment systems that are likely to be effective in removing arsenic. This may be especially important in rural areas where adverse health effects are not evident to local populations.

Key words | arsenic, private wells, residential water supply

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INTRODUCTION

The Safe Drinking Water Act and amendments apply to public water supply systems. Private water supply wells, such as domestic wells that serve single residences, are not subject to any aspect of regulation associated with the Safe Drinking Water Act, including standards for operation, testing and conformance with the maximum contaminant levels set for public health protection. Use of such wells is common in rural areas.

Recent revision of the standard for arsenic in public drinking water supplies followed debate about the health benefits of reducing the standard from the current 50 ppb concentration. The 50 ppb standard was adopted from a US

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Public Health Service guideline, as part of the development of the Safe Drinking Water Act in 1976, without the weight of evidence, rigour of literature review and cost benefit analysis that characterizes current approaches to determining maximum contaminant levels in public drinking water supplies. The health risks associated with chronic exposure to sub-acute concentrations of arsenic in drinking water have been discussed at length in several documents developed to support revision of the maximum contaminant level (NRC 1999, 2001). Health effects include cancer and non-cancer effects.

In rural areas, small urban centres are often surrounded by dispersed residences. Those living in urban centres may be served by public water supplies, while outlying homes rely on private domestic wells. Because of economies of scale and federal and state requirements, public water systems may provide water that is of substantially different quality from that obtained from private wells (Focazio *et al.* 2000), even if water is withdrawn from the same aquifer.

Approximately 25,000 people reside in Churchill County, Nevada. Of these, an estimated 11,500 are served by 16 public water supplies. The remainder, in an estimated 5,500 households, rely on private domestic water supplies (personal communication, Churchill County Planning Department, 2002). High concentrations of arsenic in water in the county have been the subject of many locally published newspaper articles. Seventy-five articles in the county's single newspaper between 1997 and 2002 discussed arsenic concentrations in water supplies, primarily related to the financial burden for local public water supplies to meet the new standard. In addition, at the time that this study was conducted federal and state agencies were investigating an abnormally high number of cases of acute lymphocytic leukaemia among residents of the county (CDC 2003). Investigations included analysis of existing data and collection of new samples to represent quality of environmental media that could be associated with the illness, including water (Seiler 2004). Investigators repeatedly noted that no evidence existed to link arsenic with cases of the illness, but also pointed out that arsenic concentrations were excessive in public supplies and urged residents to seek alternatives until effective treatment could be applied (CDC 2003).

Arsenic in groundwater in Churchill County is from natural sources, primarily eroded volcanic rock accumulated in alluvial deposits and geothermal sources. Concentrations in the largest public water supply (which serves the county seat, Fallon) exceed 100 ppb (Maurer *et al.* 1994). Fallon's public supply relies on a basalt aquifer and concentrations are fairly consistent. Treatment recently installed will substantially reduce concentrations to levels that comply with the new standard.

Studies of water quality report that arsenic concentrations are likely to vary significantly throughout the county, because of heterogeneous subsurface lithology, mineralogy and geothermal influences (Lico and Seiler 1994; Fitzgerald 2004). Private wells are primarily installed at two classes of depth in a very disjoint system of alluvial aquifers (Maurer *et al.* 1994). The alluvial aquifers are classified as *shallow* ($<$ 15 m in depth from the land surface) and *intermediate* (15–300 m in depth from the land surface) (Glancy 1986). Concentrations of arsenic vary substantially spatially, but in general have been found to be elevated relative to the 10 ppb MCL (Seiler 2004).

The types of treatment system available for removing arsenic are limited for home application. Reverse osmosis has been found to be highly effective for reducing concentrations of arsenic (Lin *et al.* 2002). At the time of the study, the National Sanitation Foundation (www.nsf.com) certified two types of home treatment system for arsenic removal. These included reverse osmosis and distillation units. Other techniques have proven to be effective, including nanofiltration, ion exchange and co-precipitation units (Waypa *et al.* 1997; Viraraghavan *et al.* 1999). However, at the time of study, household-scale units of these types were not certified for removing arsenic from home water supplies.

This study examined exposure to arsenic in water supplies provided to county residents by private domestic wells. It investigated concentrations in tap water and household consumption habits. It also investigated the prevalence of application of treatment units and compared concentrations of arsenic in tap water samples among subsets of the sampled population. These included households with treated and untreated tap water and households where participants reported consuming treated and untreated tap water. The distinction between these subsets is based on the observation that householders may choose to avoid tap water for consumption, regardless of whether treatment is applied.

METHODS

Recruitment and data collection and water sample analysis

A total of 351 households participated in the study. The study was led by the authors (hereafter referred to as the study team). A group of community volunteers assisted the study team in recruiting households. The study team placed brochures in nearly all businesses in Fallon and delivered a limited number directly to homes. Sampled households were spatially dispersed throughout the county in approximately the same pattern and density as the population (Figure 1). Approximately one-third of the participants (111/351 (31.6%)) responded to the brochure. The remaining respondents were recruited through direct intercept by community volunteers. Intercept surveys are commonly used for obtaining recreational data (Krysan *et al.* 1994). Bias in intercept surveys is possible, but extremely difficult to assess quantitatively (see Robson 1961; McFadden 1999). Our approach to evaluating potential bias involved comparison with information obtained from the 2000 national census for Churchill County.

Surveys were administered in person, at the time of tap water sampling. As an incentive participants were provided with a routine domestic analysis (value of US$100, provided by the Nevada State Health Laboratory (a certified public drinking water analysis facility)). The routine domestic analysis provides information about concentrations of major anions and cations, some metals (including arsenic) and several aesthetic qualities of water samples.

Each participant was asked questions about socio-economic characteristics (income, education level, length of residence in the county, presence of children in the household), water consumption habits, use of treatment devices and perceptions of risk associated with tap water quality and arsenic concentrations. Information sought about water consumption habits included types of use (including direct consumption from the tap, in mixed beverages and for minor uses such as making ice). A respondent was considered to consume water if they indicated that they drank or made beverages with tap water.

The questionnaire requested information about application of treatment devices. The choices included many that were not certified to be effective in removing arsenic for home use by the National Sanitation Foundation in 2002. Respondents were asked whether they treated and were asked to select the type of treatment from a list that included reverse osmosis and distillation (both of which were certified by the National Sanitation Foundation for arsenic removal), and several types of carbon-based filtration system, simple filtration systems, softeners, pH neutralizers and several types of disinfection system (Benson 2003). The other systems are effective for mitigating chemical, microbiological and aesthetic problems, but were not certified for arsenic removal. If respondents reported that they applied any type of treatment, they were considered to treat private supplies prior to delivery at the tap.

The study area was approximately 583 square kilometres and excluded the service districts of public water supplies, the largest of which served the city of Fallon (Figure 1). Approximately 10,750 people lived in the study area (US Census Bureau 2000, as reported at www.census.gov).

Sampling and analytic protocols

Tap water samples were collected from the point of most frequent use, which was usually a kitchen faucet. Samples were collected in new 500 ml bottles, provided by the project laboratory. Bottle lots were tested for arsenic residues by the project laboratory prior to distribution. Sample collection bottles contained 0.5 ml of HNO_3 (to achieve final sample pH of less than 2). Collection involved minimal purging (approximately five seconds of flow prior to collection) and no sample bottle rinsing. Arsenic concentrations were determined by EPA method 200.8 (ICP-MS) for samples with turbidity less than 1 NTU and ASTM method D2972-93B (hydride generation AA) for samples with turbidity greater than or equal to 1 NTU. The limit of detection was 3 ppb.

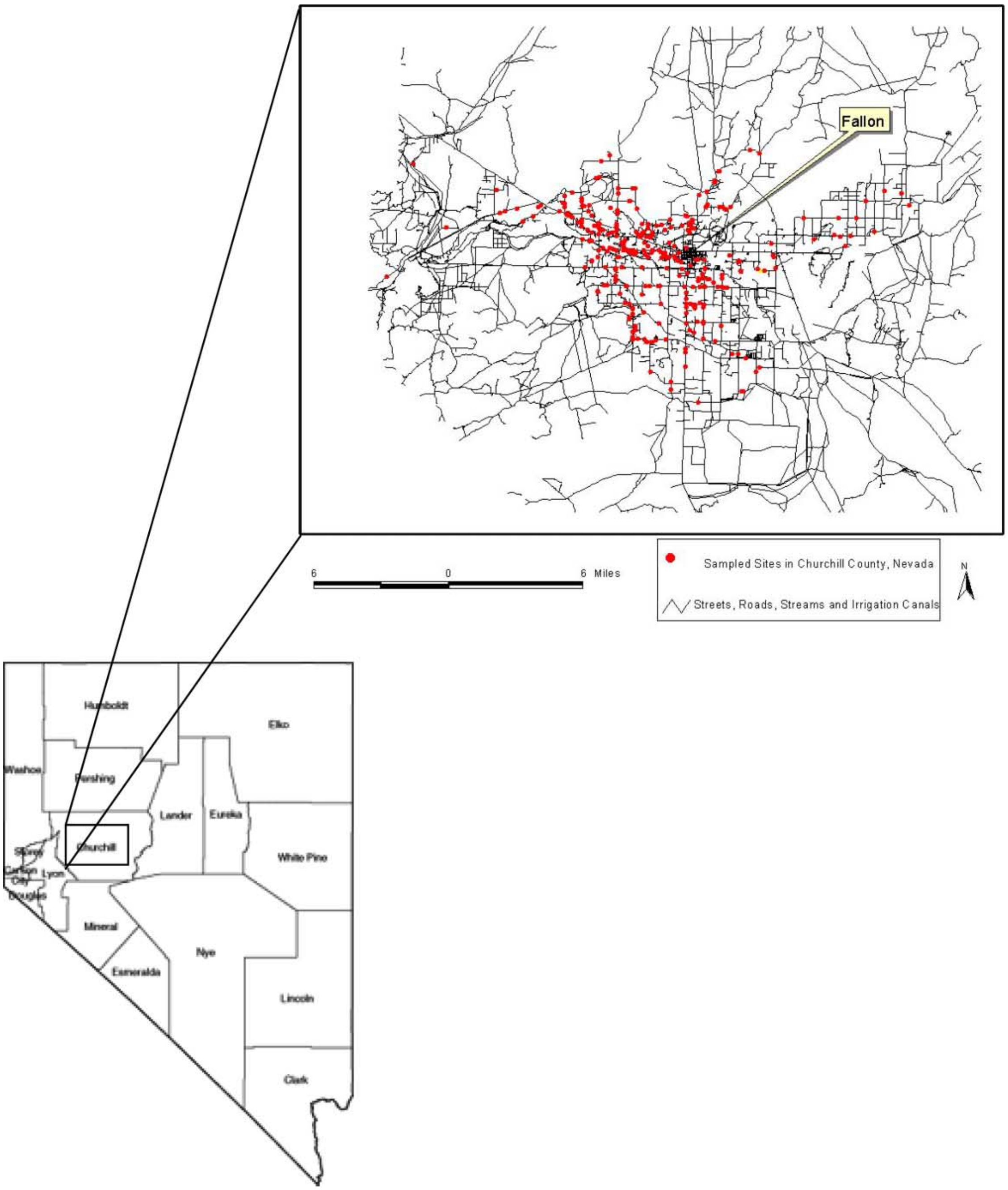

Figure 1 | State of Nevada, with study area and sampled points (inset).

Quality assurance/quality control measures within the laboratory included assessments of analytical and batch instrument performance. Analytical quality control measures bracketed each ten sample analyses with an initial performance check, a continuing calibration blank and a continuing calibration verification. The batch quality control consisted of an initial laboratory reagent blank, a laboratory fortified blank, a duplicate sample analysis and a fortified sample analysis, as a duplicate, per 20 analyses. The project laboratory released sample reports after review of analytical and batch quality assurance/quality control results conformed to laboratory criteria.

RESULTS AND DISCUSSION

Sampled and general population characteristics

The sample consisted of 351 respondents, from sampled households dispersed throughout the county (Figure 1). Comparison with data obtained during the 2000 US Census (www.census.gov) indicated discrepancies between the sample and population characteristics of county residents who were excluded from the study because they were served by public water supplies. These included under-representation of those who rented rather than owned homes (8.8% of sample, vs. 18.8% reported for the county), proportions of 18–30-year-old respondents (4.3% of sample, vs. an estimated 14.2% reported for the county) and proportions of males versus females (41% of respondents were males, vs. 51% reported for the county) (Benson 2003).

Tap water sample results

Arsenic concentrations in tap water samples were highly varied, as would be expected given the heterogeneous nature of the aquifers used for private domestic supplies (Glancy 1986; Lico *et al.* 1986; Maurer *et al.* 1994). The maximum, median and minimum concentrations of arsenic found in all samples (n = 351) were 2,100 ppb, 26 ppb and <3 ppb (the limit of detection), respectively. The distribution of sample concentrations (Figure 2) indicates that the majority of tap water samples from domestic wells (260/351, 74%) in sampled households had concentrations of arsenic that exceeded 10 ppb. Upper bounds of quartiles for the distribution of sample results are reported in Table 1.

Consumption and treatment habits and associated exposure

A majority of respondents (262/351, 75%) reported that they consumed tap water. A minority (134/351, 38%) reported treating tap water. Of those that applied treatment, a majority (116/135, 86%) consumed tap water. Approximately equivalent proportions applied reverse osmosis or distillation as a treatment (63/134, 47%) or other types of treatment. Of those that did not apply treatment, a majority (146/217, 68%) consumed tap water. Table 1 reports upper

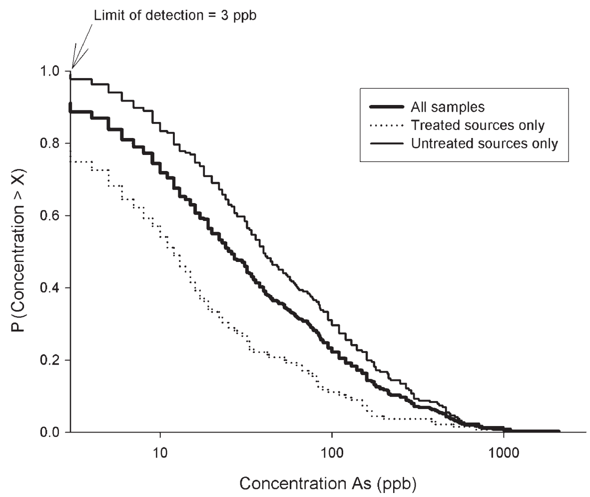

Figure 2 | Cumulative distribution of concentrations of arsenic in all samples (n = 351), samples from treated sources (n = 135) and untreated tap water samples (n = 216). Data are left censored at concentration = 3 ppb, the detection limit from project laboratory.

bounds of quartiles of concentrations for those who reported consuming water, categorized according to presence of treatment. The distribution of concentrations in consumed tap water is illustrated in Figure 3.

Likelihood of consumption and exposure given treatment

The results suggest that application of treatment effectively lowers the likelihood of exposure to concentrations of arsenic greater than 10 ppb. They also indicate, however, that those who treated supplies were more likely to consume tap water. This suggests the possibility that treatment did not reduce risk of exposure to concentrations greater than 10 ppb, given that those who applied treatment appeared to be more likely to consume tap water than those who did not apply treatment and that the median concentration of water consumed by those who treat is 12 ppb (Table 1). We tested these hypotheses using 2 × 2 contingency tables to estimate odds ratios of likelihood of consumption given treatment and likelihood of consuming greater than 10 ppb of arsenic in tap water given treatment. The results confirmed the observation that those who applied treatment were more likely to consume than those who did not treat. A respondent was approximately 6.2 times more likely to consume tap water if treatment were in place (95% confidence bounds of 3.0–12.9) relative to those

Table 1 | Distribution of arsenic concentrations reported in parts per billion (ppb) in tap water samples obtained from private domestic wells in Churchill County, Nevada

Upper bounds of quartiles	All samples	Treated	Untreated	Treated and consumed	Untreated and consumed
Minimum	ND*	ND	3	ND	3
First	10	4	17	4	14
Second (data set median)	26	13	41	12	33
Third	92	33	133	26	86
Fourth (data set maximum)	2100	870	2100	870	750
N	351	134	217	116	146

*Not detected at limit of detection = 3 ppb

who did not treat. Treatment also appeared to decrease the chances that a respondent would consume water with more than 10 ppb of arsenic relative to those who consumed water but did not treat. Those who applied treatment and consumed water were approximately 0.3 times as likely to consume arsenic in concentrations of > 10 ppb (95% confidence bounds of 0.2–0.5) than those who did not apply treatment. This reflects the difference in distributions of concentrations shown in Figure 3 and indicates that treatment is likely to reduce exposure to concentrations in excess of 10 ppb, although samples taken from approximately half the treated sources exceeded 12 ppb (Table 1).

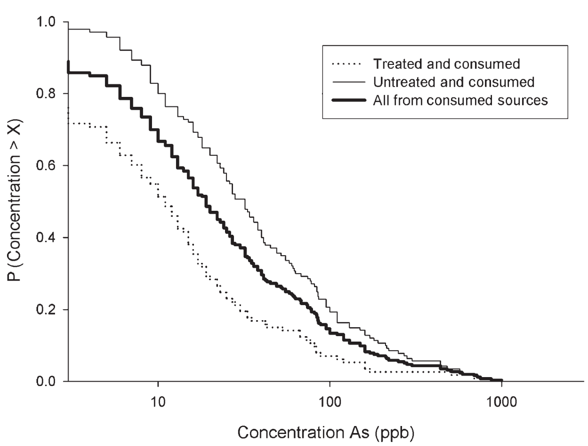

Figure 3 | Cumulative distribution of concentrations of arsenic in all samples from sources where residents reported consuming the water. These include the distributions of concentrations in all consumed sources (n = 253), samples from treated sources (n = 113) and untreated tap water samples (n = 140). Data are left censored at concentration = 3 ppb, the detection limit from project laboratory.

CONCLUSIONS

Results of the survey indicated that a majority of those who rely on private water supplies in this rural Nevada county were consuming water with concentrations of arsenic that exceeded the standard of 10 ppb for arsenic in public drinking water supplies. In addition, a minority applied treatment. In spite of publicity about arsenic and its occurrence in groundwater in the county, a majority of householders sampled appeared to ignore risks associated with consumption and did not take precautions to reduce the risks.

We speculate that this paradox (ample information about the potential for water to contain high concentrations of arsenic, coupled with the high prevalence of consumption and low prevalence of treatment systems) may be the result of a lack of local evidence that long-term exposure through consumption leads to health problems. This hypothesis may be related, in part, to length of residence in the county (median residence time for respondents was 24 years) and a lack of perceived health effects associated with long-term consumption of the water. Anecdotally, many survey respondents commented that they had been consuming water from wells with high concentrations of arsenic for extended periods (often decades). They further commented that they had not noticed adverse effects attributable to drinking water on their health or the health of acquaintances and friends. This perceived lack of health effects corresponds with what has been referred to as a lack of signal (Slovic 1987). If long-term exposure is not perceived to be associated with illness, especially among older established residents of the community, residents are likely to believe that risks of consuming water with excessive concentrations of arsenic (relative to the 10 ppb MCL) are minimal.

Although treatment in general appears to decrease the risk of being exposed to high concentrations of arsenic, application of any treatment appears to encourage consumption, in spite of the fact that some treatments may be ineffective in decreasing concentrations of arsenic. This indicates four aspects of treatment that should be understood by those relying on commonly available systems. First, many types of commonly available systems are unlikely to be effective in removing dissolved arsenic from water supplies. For example, carbon filtration systems may be very useful for removing specific types of organic contaminant, but they are unlikely to reduce concentrations of metals such as arsenic.

Second, even perfectly functioning systems designed to remove arsenic (for example, reverse osmosis systems) must be efficient in terms of percentage removal. The extreme concentrations noted in this survey and in raw groundwater in other surveys (e.g. with maxima exceeding 1,000 ppb (Seiler 2004)) would require that systems have consistently high efficiencies to reduce arsenic to safe levels. A survey carried out to test efficacy of reverse osmosis units in the county found that these were able to remove more than 95% of arsenic in 8/13 tested residential systems (R. Seiler, personal communication, 2003). However, trials with groundwater containing 700 ppb of arsenic have demonstrated that selected systems could not reduce concentrations to acceptable levels, even though removal efficiencies were high (Lin *et al.* 2002). Third, other chemical and physical factors may affect performance of reverse osmosis systems (Seiler 2004). These include solution acidity and the valence form of arsenic in solution (Kang *et al.* 2000). Fourth, reverse osmosis units must be installed and maintained correctly to be effective. If the membrane is torn or perforated the treatment system may have very little effect on arsenic concentrations.

Rural areas throughout the United States have populations that rely on private wells for household water supply. Regionally, arsenic from natural sources may occur in concentrations that are above the pending federal standard for public water supplies. This includes areas in the arid west, especially associated with iron-rich aquifer materials and the influences of geothermal waters (Welch *et al.* 2000). In areas where concentrations of arsenic have been demonstrated to be high, it may be important to conduct a focused educational effort for private well owners to ensure that they take steps needed to assess and reduce risks associated with contaminants found in tap water, including arsenic. We note that in Churchill County, Nevada, the county newspaper printed ample news about arsenic concentrations in groundwater and representatives of federal agencies investigating occurrence of acute lymphocytic leukaemia noted that arsenic levels in water supplies were a concern.

Although these types of information could be expected to raise awareness about occurrence of arsenic in groundwater supplies used by householders, they do not represent a focused educational effort aimed at changing behaviour. An educational effort could include promoting sampling efforts to determine the magnitude of arsenic concentrations at individual residences, explaining the risk associated with arsenic consumption and providing information about choices for home treatment systems that are likely to be effective in removing arsenic (including information about installation and maintenance requirements). This may be especially important in rural areas where adverse health effects linked to consuming high concentrations of arsenic in water are not evident to local populations.

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