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Arsenic consumption and health risk perceptions in a rural western U.S. area

[Forthcoming, *Journal of the American Water Resources Association*, 2006]

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Abstract

Churchill County, Nevada had approximately 23,000 residents, with an estimated 13,500 who relied on private wells for water supply in 2002. This study examined exposure to arsenic in water supplies among residents with private domestic wells and factors related to householder choice to consume tap water. It compared opinions and concerns about water quality with consumption habits and observed concentrations from tap water samples. The results from 351 households indicated that a majority (75%) of respondents consumed tap water and that a minority (38%) applied treatment. Approximately 66% of those who consumed tap water were exposed to concentrations of arsenic that exceeded 10 ppb. Water consumption was related to application of treatment. Among 98 respondents who were not at all concerned about the health effects of aqueous arsenic, 59 (60%) reported consuming

25 tap water with concentrations of arsenic exceeding 10 ppb. Conversely, among 86
26 respondents who were highly concerned about arsenic, 33 (37%) consumed tap water
27 with concentrations of arsenic exceeding 10 ppb. Results from a national sampling
28 effort showed that 620/5304 (11.7%) of private wells sampled had arsenic
29 concentrations above 10 ppb. The paradox of awareness of arsenic in water supplies
30 coupled with consumption of aqueous arsenic in concentrations of >10 ppb may be
31 common in other parts of the nation. Enhanced educational efforts, especially related
32 to tap water sampling and explanations of efficacy of available treatment, may be a
33 useful means of reducing exposure through private water supplies.

34

35 *Key terms: public health, water quality, drinking water, arsenic, metals*

36 **Introduction**

37

38 In the United States, the Safe Drinking Water Act and amendments apply to
39 public water supply systems. The standard for arsenic in drinking water recently was
40 revised from 50 to 10 ppb, effective 2006 ((40 CFR 141.62(b)(16)). The World Health
41 Organization has maintained a guideline of 10 ppb since 1993 (WHO 2004). Private
42 water supply systems, such as domestic wells that serve single residences, are not
43 subject to any aspect of regulation associated with the Safe Drinking Water Act,
44 including standards for operation, testing and conformance with the maximum
45 contaminant levels set for public health protection. Use of such wells is common in
46 rural areas throughout the United States.

47 Approximately 23,000 people reside in Churchill County, Nevada. Of these,
48 an estimated 5500 households with 13,500 residents relied on private domestic water
49 supplies in 2002 (personal comm. Churchill County Planning Department, 2002).
50 Churchill County recently attracted national attention because of concern related to an
51 abnormally large number of children diagnosed with acute lymphocytic leukemia in
52 the summer of 2000 (Steinmaus, Lu et al. 2004). Although unrelated to arsenic in
53 groundwater, investigations of the cluster led to recommendations by an expert panel
54 convened by the U.S. Centers for Disease Control and Prevention that county
55 residents consider the quality of personal supplies, with special attention to arsenic
56 (Robison, Sinks et al. 2001).

57 In Churchill County arsenic in groundwater is released from eroded volcanic
58 rock and geothermal sources. Studies of water quality have reported that arsenic
59 concentrations are commonly high and likely to vary significantly throughout the
60 county, which is partly related to the source of water (Lico and Seiler 1994).

61 Concentrations have been reported to vary over several orders of magnitude, from <1
62 ppb to more than 1000 ppb (Lico and Seiler 1994). Variation is due to heterogeneous
63 subsurface lithology, mineralogy and geothermal influences (Lico and Seiler 1994;
64 Fitzgerald 2004; Seiler 2004). Private wells pump from two alluvial aquifer systems,
65 which are recharged by applied irrigation water (Seiler and Allander 1993).

66 This study examined exposure to arsenic in water supplies among residents
67 with private domestic wells and factors related to householder choice to consume tap
68 water. It compared opinions and concerns about water quality with consumption
69 habits and observed concentrations from tap water samples.

70

71 **Methods**

72 *Recruitment and data collection and water sample analysis:* Participants were
73 recruited by direct solicitation from a research team and by flyers distributed to homes
74 and businesses in Churchill County. The recruitment strategy was designed to reach a
75 cross-section of the population, with respect to spatial distribution and socio-
76 economic characteristics. As an incentive, participants were provided with a water
77 sample analysis (value of \$100, provided by the Nevada State Health Laboratory (a
78 certified public drinking water analysis facility)). The analysis reported
79 concentrations of major anions and cations, some metals (including arsenic) and
80 several aesthetic qualities.

81 Participants were asked questions about household characteristics and
82 opinions (including consumption of home water supplies, use of treatment devices,
83 level of concern about drinking water quality in general and arsenic in water supplies,
84 and opinion of health risks associated with drinking water supplies (Benson 2003)).
85 Questions about water consumption habits asked respondents about types of use

(ranging from direct consumption from the tap and in mixed beverages to minor uses such as making ice). Respondents were considered to consume tap water if they indicated that they drank or made beverages with tap water.

The questionnaire also requested information about water treatment choices. At the time of the survey (2002) the National Sanitation Foundation (www.nsf.com) recognized only reverse osmosis and distillation as being effective treatments to remove arsenic. Respondents were asked whether they treated home supplies and were asked to select the type of treatment applied from a list that included reverse osmosis, distillation, several types of carbon-based filtration systems, simple filtration systems, softeners, pH neutralizers and several types of disinfection systems (Benson 2003). For preliminary data analysis (see Figure 1), application of treatment was considered as a simple binary classification variable, with respondents either treating water by any of the means noted above, or not treating water. For purposes of data analysis related to health risk perception (see Table 3 and statistical analyses in the “Results” section) answers from respondents about treatment were coded in one of three categories: (a) treatment applied was considered to be effective in removing arsenic, (b) no treatment was applied, or (c) the treatment applied was not considered to be effective in removing arsenic.

The study area, within the Churchill County boundary, was approximately 225 square miles and excluded the service districts of public water supplies, the largest of which served the city of Fallon (the county seat (**Figure 1.**)). Approximately 10,750 people lived in the study area (U.S. Census 2000, available at www.census.gov).

Sampling and analytic protocols: Tap water samples were collected from the point of most frequent water use in the home identified by the respondent, which was usually a

111 kitchen faucet. Collection involved minimal purging to simulate home use habits
112 (approximately five seconds of flow prior to collection). Arsenic concentrations were
113 determined by the Nevada State Health Laboratory (a certified drinking water analysis
114 facility) using EPA method 200.8 (ICP-MS) for samples with turbidity less than 1
115 NTU and ASTM method D2972-93B (Hydride generation AA) for samples with
116 turbidity greater than or equal to 1 NTU.

117

118 **Results**

119 *Sampled and general population characteristics:* The sample consisted of 351
120 respondents, from households dispersed throughout the county (**Figure 1**).
121 Comparison with results of the 2000 U.S. Census (www.census.gov) indicated slight
122 discrepancies between the sample and population proportions of homeowners and
123 renters, proportions of 18-30 year old respondents, proportions of those with less than
124 a high school education, proportions of those with income exceeding \$75,000 per year
125 and proportions of males versus females (Benson 2003). **Table 1** compares sampled
126 with population demographic characteristics.

127 *Tap Water Sample Results:* Arsenic concentrations in tap water samples were
128 highly varied (ranging from < 3 ppb (analytical detection limit) to 2100 ppb (**Table**
129 **2**), as would be expected given the heterogeneous nature of the aquifers used for
130 private domestic supplies (Glancy 1986; Lico, Welch et al. 1986; Maurer, Johnson et
131 al. 1994; Seiler 2004). The distribution of sample concentrations (**Figure 2**) indicates
132 that the majority of tap water from domestic wells in Churchill County had
133 concentrations of arsenic that exceeded 10 ppb. The minima, medians and maxima
134 for each group depicted in reported in **Table 2**.

135 *Consumption, Treatment and Exposure to Aqueous Arsenic:* A majority of

136 respondents (262/351, 75%) reported that they consumed tap water. A minority
 137 (134/351, 38%) reported treating tap water. Of those that applied any type of
 138 treatment, a majority (116/134, 86%) consumed tap water. Of those who applied
 139 treatment, 63/134 (47%) applied reverse osmosis (62 respondents) or distillation
 140 (1 respondent). Of those that did not apply treatment, a majority (146/217, 68%)
 141 consumed tap water. **Table 2** reports the minimum, median and maximum
 142 concentrations for those who reported consuming tap water, categorized according to
 143 presence of treatment. The distribution of concentrations in tap water consumed by
 144 respondents is presented in **Figure 2**.

145 *Concern about water quality and influence on choice to consume tap water:*
 146 The questionnaire administered to survey participants requested information about
 147 application of treatment and treatment type, levels of concern about water quality in
 148 general and arsenic in water specifically, perceptions of health risks associated with
 149 drinking water and whether or not respondents consumed tap water (**Table 3**). We
 150 sought relationships between responses to these questions using correspondence
 151 analysis based on the χ^2 distribution with cross-tabulated results. **Table 3** contains
 152 summary information received from respondents about each of these topics. Null
 153 hypotheses tested focussed on statistical independence between the following
 154 factors:

- 155 • levels of concern about water quality in general and concern specifically
 156 about arsenic in water supplies;
- 157 • application and type of treatment applied and whether respondents
 158 consumed tap water;
- 159 • perception of health risks posed by drinking water supplies and whether
 160 respondents consumed tap water; and

- perception of health risks posed by drinking water supplies and concern about arsenic in water supplies.

Results of Analysis of Cross-tabulated Data

Levels of concern about water quality in general and concern specifically

about arsenic in water supplies: The relationship between concern about water quality in general and concern specifically about arsenic in water favored rejection of the null hypothesis that these concerns are independent ($p=0.000+$). Although there are many types of concerns related to quality of water from private wells in Churchill County, arsenic is a predominant issue. In fact, records kept of inquiries about water quality by a water supply specialist working for University of Nevada Cooperative Extension indicate that the vast majority of questions and concerns between March 2003 and February 2005 were related to arsenic in water (A. Fisher, University of College of Agriculture, Biotechnology and Natural Resources, Cooperative Extension, Fallon, Nevada, personal communication, 7/2005). The questions and concerns may be prompted by ongoing news coverage of arsenic in public and private water supplies. In fact, 113 news stories from March 2003 – July 2005 focussed on or mentioned arsenic in groundwater (A. Fisher, *ibid.*).

Application and type of treatment applied and whether respondents consumed

tap water: The correspondence between treatment of water and consumption is especially strong. The null hypothesis of independence of these factors was rejected in favor of the alternative (the factors are not independent) at $p=0.000+$. Odds ratios (with 95% confidence intervals) of consumption given any treatment, correct treatment and other treatment indicated that respondents were 2.88 (95% confidence interval: 1.64–5.07) times more likely to consume tap water if any treatment were in place, 4.52 (1.86–10.99) times more likely to consume if treatment recognized as

186 being effective for removing arsenic were in place and 2.12 (1.10–4.13) times more
 187 likely to consume if treatment not recognized as being effective for removing arsenic
 188 were in place. This suggests that householders who invested in treatment systems,
 189 especially those considered to be effective for removing arsenic, were more likely to
 190 consume tap water than those who did not apply treatment.

191 *Perception of health risks posed by drinking water supplies and whether*
 192 *respondents consumed tap water:* The relationship between perception of health risks
 193 posed by drinking water supplies and whether respondents consumed tap water was
 194 not independent ($p=0.000+$). In fact, respondents were 5.28 (2.42–11.48) times less
 195 likely to consume tap water if they held the opinion that there were health risks
 196 associated with their drinking water, compared with those who felt there were not
 197 health risks or didn't know whether there were health risks.

198 *Perception of health risks posed by drinking water supplies and concern about*
 199 *arsenic in water supplies:* The null hypothesis of independence was rejected at a high
 200 level of significance ($p=0.000+$), suggesting that these are related. A respondent was
 201 approximately 0.32 (0.10–0.99) times as likely to be unconcerned or not know about
 202 health risks associated with drinking water if the same respondent was very concerned
 203 about arsenic in drinking water. This suggests that respondents recognized that
 204 arsenic in water supplies could be a health threat, which corresponded with the results
 205 from the first hypothesis tested above.

206

207 **Discussion**

208 Among these respondents, levels of concern about both arsenic and water
 209 quality in general were correlated, suggesting that a respondent's level of concern
 210 about water quality mirrored the level of concern about arsenic. Awareness of arsenic

211 as a potential contaminant in local groundwater may have been related to the amount
212 of information available through television, radio and especially locally distributed
213 newspapers. However, the levels of concern about water quality and arsenic in water
214 were not uniformly high. In fact, the majority of responses to the question of level of
215 concern about arsenic in drinking water (**Table 3**) was distributed at the extremes,
216 with approximately 28% of respondents being not-at-all concerned and 25% being
217 highly concerned. Levels of concern about water quality in general and arsenic were
218 correlated through a distribution that had clusters of respondents at the extremes, with
219 no significant trends.

220 In spite of a fairly constant flow of public information about the occurrence of
221 arsenic in groundwater, approximately 28% of respondents (98) were not concerned at
222 all about arsenic in water. Among this group of 98, 59/98 (60%) reporting consuming
223 tap water that testing showed had concentrations of arsenic greater than 10 ppb.
224 Conversely, among those who reported being highly concerned about arsenic in water
225 (86 respondents), 33/86 (37%) respondents reported consuming tap water, with
226 concentrations of arsenic that testing showed contained > 10 ppb. This suggested
227 that concern led to reduced likelihood of consumption, though a significant proportion
228 of those who were highly concerned consumed tap water that exceeded the standard
229 for arsenic.

230 Among those who indicated a high level of concern about arsenic in water
231 there was a significant gap in understanding about water quality. In spite of having
232 high levels of concern, respondents exposed themselves to arsenic through
233 consumption at home. This paradox indicates a lack of understanding about the true
234 concentration of arsenic in home drinking water supplies among this subset of the
235 respondents, which is further reflected in responses to a question asked about the

236 standard for arsenic. Respondents were asked to identify the concentration and units
237 of the standard. Although there appears to be a general awareness of arsenic as a
238 contaminant in drinking water supplies, respondents were unclear about the numerical
239 value of concentration and units (**Figure 3**). In fact, 77.5% (272/351) did not cite
240 either the correct units or numerical value; a minority of respondents 12.0% (42/351)
241 was able to correctly identify both. This suggests that respondents based their
242 decision to consume on incomplete information about the actual concentrations of
243 arsenic in water and the significance of concentrations.

244 Although treatment of any kind led to decreased overall concentrations in tap
245 water (**Figure 2**) respondents who used appropriate types of treatment (reverse
246 osmosis or distillation) were exposed to concentrations of arsenic that exceeded the
247 standard. Among those who applied reverse osmosis or distillation and consumed tap
248 water (63), 34/63 (54%) were exposed to concentrations >10 ppb. Among those who
249 applied reverse osmosis or distillation that testing showed contained more than 10
250 ppb, 30/63 (48%) felt that their water did not contain concentrations of arsenic that
251 exceeded 10 ppb. This suggests that the investment in treatment led to a false sense
252 of security about home water supplies.

253 Although reverse osmosis is recognized as an effective means of reducing
254 concentrations of arsenic in water, it may not be effective in producing water that
255 meets the 10 ppb standard if groundwater concentrations are very high. This has been
256 demonstrated in other sampling surveys conducted in the county (such as
257 <http://nevada.usgs.gov/fallon/FallonFeb03.ppt> -- see slide 4 comparing arsenic in
258 influent groundwater with reverse osmosis treated water concentrations). As an
259 example, if starting concentrations of arsenic are > 1000 ppb, reverse osmosis units
260 operating at peak efficiency ($\geq 99\%$ reduction in concentrations of arsenic in influent

261 groundwater) may not reduce concentrations to less than the 10 ppb maximum
262 contaminant level.

263 Although focussed on a small rural area in the western United States, the
264 apparent paradox of concern about arsenic and consumption of tap water with
265 concentrations that exceed the national standard for arsenic in public water supplies
266 may have important implications for other areas. Private wells associated with
267 residences serve a minority of the U.S. population, especially in rural areas. Of 5304
268 private, domestic wells sampled in the U.S. as part of the National Water Quality
269 Assessment program from 1973 – 2001 across the United States (including Hawaii,
270 Puerto Rico and Alaska) arsenic concentrations in 620 equalled or exceeded 10 ppb
271 (USGS 2001). This proportion is not representative of all private wells in the United
272 States, but it indicates that private wells in other areas of the country also produce
273 water that is contaminated with arsenic.

274 Although Churchill County represents an extreme, in terms of concentrations
275 of arsenic that occur in groundwater, publicity about arsenic and exposure through
276 private water supplies, it suggests that, even in the presence of well-publicized
277 concerns about the potential health effects associated with groundwater consumption,
278 private well owners may be unaware of the significance of standards that apply to
279 public water supplies and the potential health effects of contaminants in their drinking
280 water. It is also possible that homeowners have a false sense of security related to
281 application of treatment that may not remove contaminants that cannot be readily
282 sensed by taste or odor. This suggests that educational efforts are needed to help
283 those who rely on private water supplies understand treatment techniques, including
284 expectations for contaminant removal. It also suggests that those who rely on private

285 wells should be encouraged to test water delivered to commonly used taps in the
286 home to evaluate the quality of water that is actually consumed.

287

288

289

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335 **Figure 1:** State of Nevada, with study area and sampled points (inset)

336 **Figure 2:** Distributions of concentrations of arsenic in all tap water samples, treated
337 and untreated tap water samples and samples from tap water consumed by
338 respondents from treated and untreated sources. Non-detections are shown at half the
339 laboratory detection limit (1.5 of 3 ppb). **Table 1** includes minimum, medium and
340 maximum values for each group.

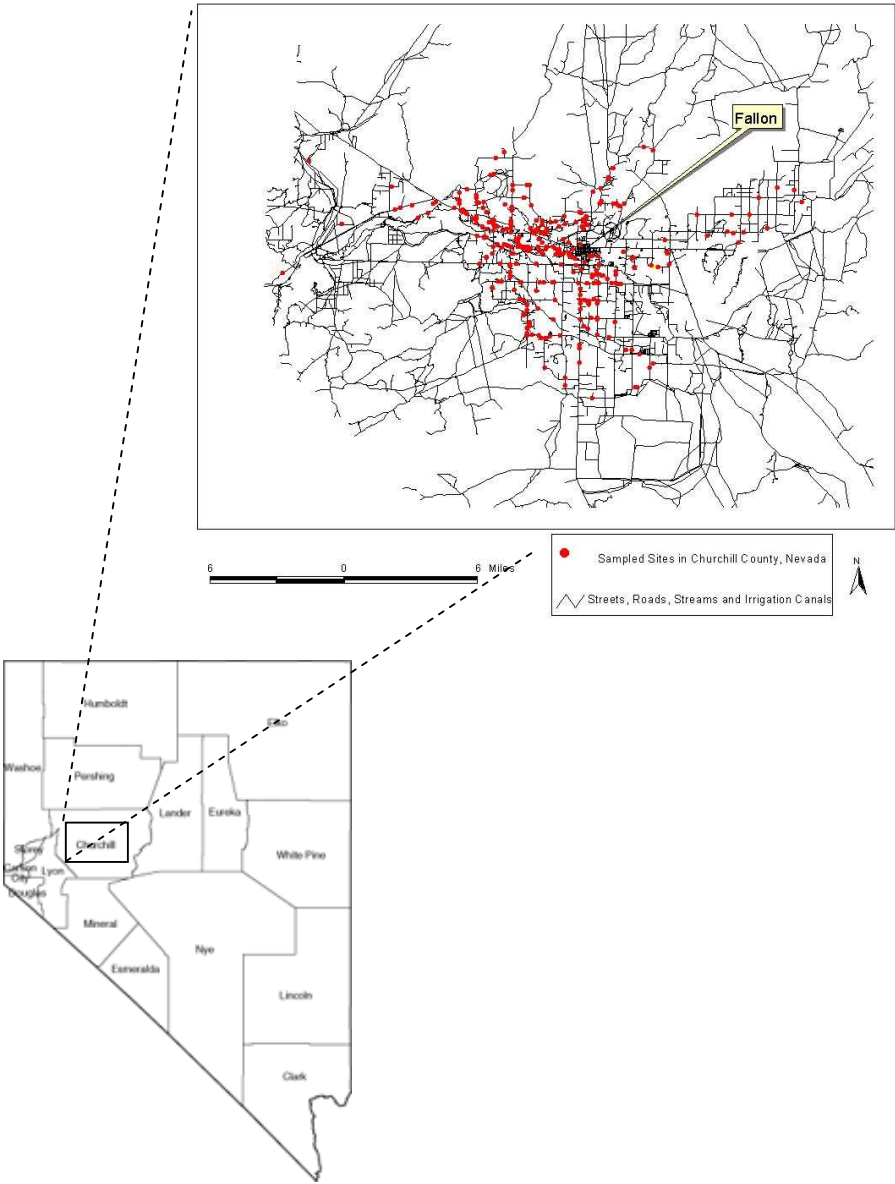
341 **Figure 3:** Respondents were asked to identify the pending maximum contaminant
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343 both units and concentration correctly, while the remainder could identify units or
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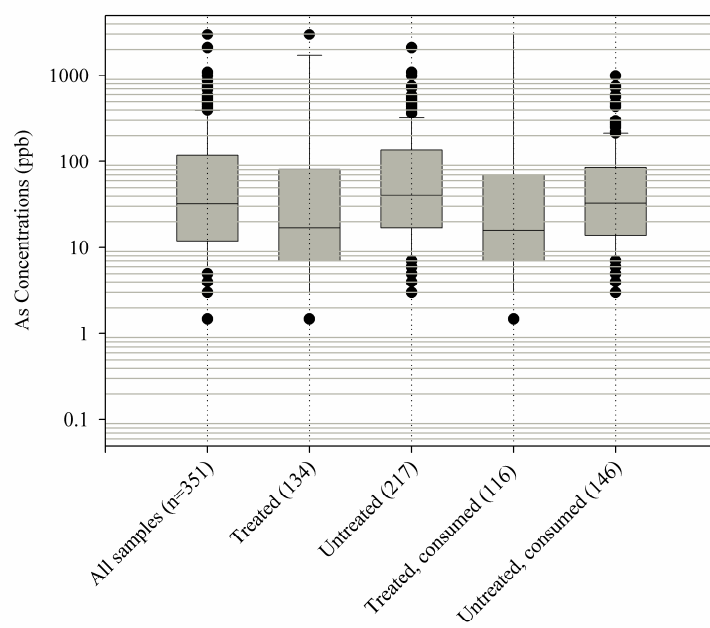
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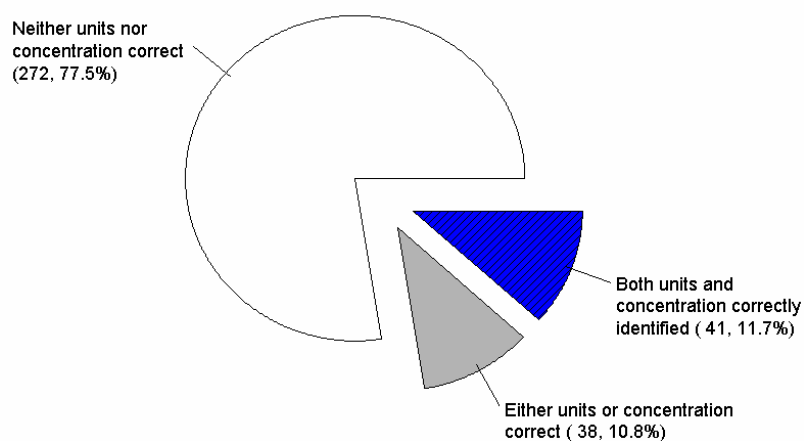
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363 level for arsenic in public water supplies. A minority (11.7%) was able to
364 identify both units and concentration correctly, while the remainder could
365 identify units or concentration or neither.



366

367

368 **Table 1:** Demographic characteristics of sample and population and Churchill

369 County, Nevada in 2002 and 2000, respectively.

Demographic Characteristic	Sample ¹	Population ²
Median Age (years)	58 ³	34.7
Sex ratio (M/F)	41.0%/59%	50.2%/49.8%
Homeownership (%owners/%renters)	91.2%/8.8% ⁴	65.8%/34.2%
Median education	Bachelor's degree	Between "completed high school degree" and "some college"
Median income	\$50,000 ⁵	\$40,808
Households with children <18 years old	37.6%	38.9%

370

¹ Benson, M. 2003. Arsenic in Churchill County, Nevada: Risk Factors Associated with Consumption of Tap Water. M.S. Thesis, University of Nevada, Reno, NV.

² US Bureau of Census, 2005. Profile of Selected Characteristics -- Churchill County. <http://quickfacts.census.gov/qfd/states/32/320011k.html>

³ No respondents younger than 18 years old were included in the sample; the US Bureau of Census (see footnote 1) reports that this fraction comprises ca. 30% of the county population.

⁴ Rental units are most prevalent within the bounds of public water supply systems (primarily the city of Fallon, NV), which was excluded from the study.

⁵ Median is drawn from classes of income reported by 293/351 respondents. The remainder chose not to report income.

Table 2: Minimum, median and maximum concentrations of arsenic (ppb) in tap water samples obtained from Churchill County, Nevada.

	All Samples	Treated	Untreated	Treated and Consumed	Untreated and Consumed
Minimum	< 3	< 3	3	< 3	3
Median	26	13	41	12	33
Maximum	2100	870	2100	870	750
n	351	134	217	116	146

375 **Table 3:** Summary of responses related to hypotheses tested

376 **Application of Treatment, and Treatment Type**

Treatment applied and considered effective in removing arsenic (National Sanitation Foundation 2002 (www.nsf.com))	63 (25.0%)
Treatment applied, not considered to be effective for removing arsenic	71 (20.2%)
No treatment applied	217 (61.8%)

377

378 **Level of concern about water quality**

379 *Q: "How concerned are you about your water quality?" (1 – 5 = very concerned)*

1	2	3	4	5
63 (17.9%)	42 (11.9%)	100 (28.5%)	41 (11.7%)	105 (29.9%)

380

381 **Level of concern about arsenic in water**

382 *Q: "On a scale of 1 to 5, how concerned about you about the level of arsenic in your*
 383 *water?" (1 – 5 = high)*

1	2	3	4	5
98 (27.9%)	43 (12.2%)	91 (25.9%)	33 (9.4%)	86 (24.5%)

384

385 **Perception of health risks associated with drinking water**

386 *Q: "Are there any health risks associated with drinking your water?"*

No perceived health risks	Unsure	Perceived health risks
76 (21.7%)	245 (69.8%)	30 (8.5%)

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