Arsenic Exposure After Switching to Bottled Water or Using POU Treatment

“Everything but the Kitchen Sink”

Andrew Smith, SM, ScD
Columbia University
September 19, 2016
50% of Maine residents rely on private well water.

10% of wells statewide have >10ug/L arsenic.

Some wells have very high arsenic levels (> 500ug/L).
Water Exposure Pathways

- Drinking and beverage
- Cooking
- Bathing and showering
- Incidental exposures
Common Mitigation Methods

- **Switch to bottled water**
  - $1000 - $5000 per year for a 4 person household

- **Point-of-use (POU)**
  - Cost: $600 - $1700
  - M&O: $50 - $200 / yr

- **Point-of-entry (POE)**
  - Cost: $2000 - $10,000
  - M&O: $150 - $1200 / yr
Residual Arsenic Exposure Study  
Study Questions

1. Does untreated well water remain a significant arsenic source post mitigation?

2. Is bathing a significant exposure pathway?

3. When should we recommend use of a POE treatment system?
Methods
Participant Recruitment

• Households on wells

• Families with children <6 years

• Households identified by:
  – State laboratory test results
  – Treatment company referrals
  – Calls to Maine CDC
  – State birth records
## Methods

### 3-day Diet and Bathing Diary

**Day 3**

<table>
<thead>
<tr>
<th>Daily Bathing (@Home)</th>
<th>Time of day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower or Bath (circle one)</td>
<td>Minutes</td>
</tr>
<tr>
<td>shower</td>
<td>20</td>
</tr>
<tr>
<td>shower</td>
<td>bath</td>
</tr>
<tr>
<td>shower</td>
<td>bath</td>
</tr>
</tbody>
</table>

**Daily Food & Beverages**

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
<th>Water source (if made with water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>orange juice</td>
<td>4 fl oz.</td>
<td>reuse container</td>
</tr>
<tr>
<td>cereal + milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>english muffin</td>
<td>1/2</td>
<td></td>
</tr>
<tr>
<td>pear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>grilled cheese sandwich on wheat</td>
<td>3/4</td>
<td></td>
</tr>
<tr>
<td>2 pear halves canned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>milk</td>
<td>6 fl oz.</td>
<td></td>
</tr>
<tr>
<td>tomato soup (w/ milk)</td>
<td>6 fl oz.</td>
<td></td>
</tr>
<tr>
<td>water</td>
<td>3 fl oz.</td>
<td></td>
</tr>
<tr>
<td>cheese + crackers</td>
<td>1/3 cup</td>
<td></td>
</tr>
<tr>
<td>milk</td>
<td>4 fl oz.</td>
<td></td>
</tr>
<tr>
<td>pasta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerry meat sauce</td>
<td></td>
<td></td>
</tr>
<tr>
<td>beet vegetables (beets) + pepper, cucumber (canned) + milk</td>
<td>3 fl oz.</td>
<td></td>
</tr>
<tr>
<td>ginger snaps</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
| water | | | reuse container

- **Young children by adult proxy**
- **Told to avoid seafood**
- **Identify source of all water consumed**
Dietary Arsenic Sources

- Rice and rice products
- Seafood and chicken
- Juices and wine
- Vegetables
### Methods

**Household Survey**

#### Home Water Use

19. When you cook at home do you use any of the following? I will read the different types of water:

- **19a. Plain unfiltered tap water from your home’s water supply?**
  - 0 = No (Go to 19b)
  - 1 = Yes (Go to 19a1 and 19a2)
  - 8 = Refused
  - 9 = Don’t know

- **19a1. How often?**
  - 1 = Always
  - 3 = Half of the time (2/4 time)
  - 8 = Refused
  - 9 = Don’t know
  - 2 = Most of the time (3/4 time)
  - 4 = Infrequently (1/4 time)

- **19a2. Are all foods prepared with this tap water?**
  - 0 = No. Specify which foods you prepare with this water. Specify: ________________
  - 1 = Yes

- **Habitual water use prior to diet diary**
- **Other potential sources of arsenic exposure**
- **Water treatment system info**
Methods
Water Samples

Analyzed for total arsenic
– Untreated water
– Treated water
– Bottled water
– Other water
Methods
Urine Samples

First morning void

 Analyzed for:

$\text{As}^{3+}$, $\text{As}^{5+}$
MMA, DMA
AsB, AsC
total As
creatinine
Methods
Statistical Modeling

• Multivariate Linear regression
• Generalized Estimating Equations (clusters)
• Dependent variables:
  – “summed” urinary arsenic measures
  – “subtracted” urinary arsenic measure
• Independent variables:
  – water arsenic concentration
  – water consumption
  – bathing time
  – selected dietary foods (rice, juice, seafood)
  – gender, age, creatinine
  – interaction terms
Results

Study Participants

- **135** children age 1-7 years
- **55** children age 8-17 years
- **183** adults age ≥ 18 years
- **167** Households
Results

Untreated Water Arsenic Levels
Results
Treated Water Arsenic Levels
Results
Bathing Type and Time

- Total Time Spent Bathing
  - Age Group: 1-7, 8-17, Adults 18+

- Total Time Spent Showering
  - Age Group: 1-7, 8-17, Adults 18+
## Results
### Urinary Arsenic Species

<table>
<thead>
<tr>
<th>Arsenic species</th>
<th>Children (age 1-17) n = 190</th>
<th>Adults (age ≥18) n = 183</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median urinary As (ug/L)</td>
<td>95&lt;sup&gt;th&lt;/sup&gt; Percentile</td>
</tr>
<tr>
<td>Total urinary As</td>
<td>12.2</td>
<td>35.5</td>
</tr>
<tr>
<td>As&lt;sup&gt;3+&lt;/sup&gt;</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>As&lt;sup&gt;5+&lt;/sup&gt;</td>
<td>0</td>
<td>1.3</td>
</tr>
<tr>
<td>DMA</td>
<td>7.1</td>
<td>21.1</td>
</tr>
<tr>
<td>MMA</td>
<td>0</td>
<td>4.0</td>
</tr>
<tr>
<td>Arsenobetaine</td>
<td>0</td>
<td>6.8</td>
</tr>
<tr>
<td>Arsenocholine</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trimethylarsine</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Arsenic Urinary Measures

- Summed = $\text{As}^{3+} + \text{As}^{5+} + \text{MMA} + \text{DMA}$
- Subtracted = Total As $-$ AsB

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Urinary As Summed (ug/L)</th>
<th>Urinary As Subtracted (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7 (n = 135)</td>
<td>12.96 ± 8.59</td>
<td>14.49 ± 11.2</td>
</tr>
<tr>
<td>≥18 (n = 183)</td>
<td>9.60 ± 7.41</td>
<td>11.62 ± 10.3</td>
</tr>
</tbody>
</table>
1. Does untreated well water remain a significant arsenic source post mitigation?

2. Is bathing a significant exposure pathway?

3. When should we recommend use of a POE treatment system?
## Results

Regression Modeling – Untreated Water Arsenic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>p value</th>
<th>Estimate</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated water [As], (ug/L)</td>
<td>0.002</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Untreated water consumption, (L)</td>
<td>-0.787</td>
<td>0.097</td>
<td>-0.144</td>
<td>0.570</td>
</tr>
<tr>
<td>Untreated water [As] × consumption, (ug)</td>
<td>0.021</td>
<td>0.024</td>
<td>0.022</td>
<td>0.019</td>
</tr>
<tr>
<td>Untreated water from cooking, (L)</td>
<td>1.137</td>
<td>0.184</td>
<td>-1.517</td>
<td>0.101</td>
</tr>
<tr>
<td>Untreated water [As] × water from cooking,(ug)</td>
<td>0.012</td>
<td>0.154</td>
<td>0.040</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Dependent Variable = Subtracted Arsenic Measure
Modeling controlled for treated water arsenic, gender, age, diet, creatinine, and age × creatinine
Predictive modeling of “average” study participant versus average participant not reporting consumption of untreated water use.
Residual Arsenic Exposure Study
Study Questions

1. Does untreated well water remain a significant arsenic source post mitigation?

2. Is bathing a significant exposure pathway?

3. When should we recommend use of a POE treatment system?
Bathing
Exposure Pathways
## Results

### Regression Modeling – Bathing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>p value</th>
<th>Estimate</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Children Age 1-7 (n = 135)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathing-children, Showering-adults (hours)</td>
<td>0.048</td>
<td>0.664</td>
<td>-0.026</td>
<td>0.872</td>
</tr>
<tr>
<td>Bathing/showering × Untreated water [As] (hours × ug/L)</td>
<td>0.001</td>
<td>0.635</td>
<td>-0.001</td>
<td>0.257</td>
</tr>
<tr>
<td>Number of baths/showers</td>
<td>-0.022</td>
<td>0.592</td>
<td>-0.015</td>
<td>0.641</td>
</tr>
<tr>
<td><strong>Adults Age ≥ 18 (n = 183)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent Variable = Subtracted Arsenic Measure
Modeling controlled for water arsenic, gender, age, diet, creatinine, and age × creatinine
## Results

Regression Modeling – Bathing Hours Stratified by Water As

<table>
<thead>
<tr>
<th>Untreated Water Arsenic</th>
<th>Bathing Hour Coefficient</th>
<th>Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7 - &lt; 22 ug/L (N=31)</td>
<td>0.170</td>
<td>0.251</td>
</tr>
<tr>
<td></td>
<td>0.251</td>
<td>-0.120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.461</td>
</tr>
<tr>
<td>22 - &lt; 58 ug/L (N=31)</td>
<td>0.062</td>
<td>0.895</td>
</tr>
<tr>
<td></td>
<td>0.895</td>
<td>-0.866</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.991</td>
</tr>
<tr>
<td>≥ 58 ug/L (N=32)</td>
<td>0.224</td>
<td>0.526</td>
</tr>
<tr>
<td></td>
<td>0.526</td>
<td>-0.468</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.915</td>
</tr>
</tbody>
</table>

Dependent Variable = Subtracted Arsenic Measure  
Modeling controlled for gender, age, diet, creatinine, and age × creatinine
Results
Regression Modeling – Diet

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
<th>Estimate</th>
<th>p value</th>
<th>Parameter</th>
<th>Estimate</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice consumption (grams dry rice)</td>
<td>Children Age 1-7 (n = 135)</td>
<td>0.007</td>
<td>&lt;.0001</td>
<td>Adults Age ≥ 18 (n = 183)</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Apple juice consumption (L)</td>
<td>Children Age 1-7 (n = 135)</td>
<td>0.199</td>
<td>0.177</td>
<td>Adults Age ≥ 18 (n = 183)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Seafood consumption (previous week)</td>
<td>Children Age 1-7 (n = 135)</td>
<td>0.016</td>
<td>0.868</td>
<td>Adults Age ≥ 18 (n = 183)</td>
<td>0.266</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Dependent Variable = Subtracted Arsenic Measure
Modeling controlled for water arsenic, gender, age, diet, creatinine, and age × creatinine
Results
What’s Going on with Children?

Predictive modeling of “average” study participant versus average participant not reporting consumption of untreated water use.

Children Age 1-7

- Average Child
- No Untreated Water Use

Predicted Urinary Arsenic (µg/L)

Untreated Water Arsenic Concentration (µg/L)
Could it be exposure prior to 3-day diary?

<table>
<thead>
<tr>
<th>Untreated water consumption comparison</th>
<th>Estimate</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All children (n=135)</td>
<td>0.0021</td>
<td>0.001</td>
</tr>
<tr>
<td>Children reporting no untreated water consumption (n=56)</td>
<td>0.0023</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Dependent Variable = Subtracted Arsenic Measure
Modeling controlled for treated water arsenic, gender, age, diet, creatinine, and age × creatinine
Could it be unreported consumption?

<table>
<thead>
<tr>
<th>Untreated water As level stratification</th>
<th>Parameter</th>
<th>Estimate</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household untreated water [As] &lt;40ug/L (n=66)</td>
<td>Untreated water [As] (ug/L)</td>
<td>-0.0014</td>
<td>0.820</td>
</tr>
<tr>
<td>Household untreated water [As] ≥40ug/L (n=69)</td>
<td></td>
<td>0.0022</td>
<td>0.012</td>
</tr>
</tbody>
</table>
1. Does untreated well water remain a significant arsenic source post mitigation?

2. Is bathing a significant exposure pathway?

3. When should we recommend use of a POE treatment system
Results
How much residual arsenic exposure is too much?

Predicted Summed Urinary As Levels for the Average Adult Age ≥18 (NHANES 20 Years and Older Age Group Comparison)
Results
How much residual arsenic exposure is too much?

Predicted Summed Urinary As Levels for the Average Child Age 1-7
(NHANES 6-11 Year Age Group Comparison)
Conclusions

• Clear evidence of water-related arsenic exposure among families relying on POU treatment systems or bottled water.

• Exposure resulted in part from occasional use of untreated water, but also unquantified water-related pathways.

• Bathing was NOT a significant exposure pathway for children or adults.

• Private well owners need to practice vigilance in avoiding use of untreated water, especially if arsenic levels > 40 µg/L, and especially if children present.
Assessing arsenic exposure in households using bottled water or point-of-use treatment systems to mitigate well water contamination

Andrew E. Smith a,*, Rebecca A. Lincoln a, Chris Paulu a,b, Thomas L. Simones a, Kathleen L. Caldwell c, Robert L. Jones c, Lorraine C. Backer d

a Maine Department of Health and Human Services, Maine Center for Disease Control and Prevention, 286 Water Street, Augusta, ME 04333, USA
b University of Southern Maine, Muskie School of Public Service, PO Box 9300, Portland, ME 04104-9300, USA
c Centers for Disease Control and Prevention, National Center for Environmental Health, Inorganic and Radiation Analytical Toxicology Branch, 4770 Buford Highway NE, MS F-18, Chamblee, GA 30341, USA
d Centers for Disease Control and Prevention, National Center for Environmental Health, Health Studies Branch, 4770 Buford Highway NE, MS F-60, Chamblee, GA 30341, USA
If Questions

Andrew Smith, SM, ScD
State Toxicologist
Tel: (207) 287-5189
Email: andy.e.smith@maine.gov
Progress on Testing Wells for Arsenic
Why do people test?

- **Check Safety**: 41.8%
- **Bought Home**: 27.2%
- **Other**: 16.8%
- **Regularly Test**: 10.4%
- **Problem**: 3.8%
Outreach to Promote Testing

- wellwater.maine.gov
  - Print materials
  - Video
  - Webinar trainings

- Toxicology Consults
  866-292-3474

- Targeted Mailing
Make Data Available

Figure (a)

Figure (b)