ARSENIC IN PRIVATE WELLS IN NH

YEAR 1 FINAL REPORT
Public Health Contract
Annual Performance Report
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ACKNOWLEDGMENTS

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INTRODUCTION

In New Hampshire, more than 40 percent of the population depends on private wells for their water supply.[1,2] The Safe Drinking Water Act does not grant the U.S. Environmental Protection Agency (EPA) authority to regulate private wells in the same manner as public water supply systems. Thus, unless state or local authorities have enacted regulations, the onus is on individual households to undertake regular testing for drinking water contaminants and to apply treatment as necessary.

Arsenic is a contaminant found in untreated well water that is of particular concern.[3] Arsenic is a Class 1 carcinogen[4] and it ranks number one on the 2013 Priority List of Hazardous Substances published by the Agency for Toxic Substances and Disease Registry.[5] Based on the potential adverse effects of arsenic on the health of humans and the frequency and level of arsenic occurrence in public drinking water systems (and the level that may be achieved with the use of the best available technology), the EPA has set the arsenic maximum contaminant level (MCL) for public drinking water systems at 10 parts per billion (ppb).[6]

In NH, past studies estimate that a relatively high number of randomly selected private bedrock wells contain concentrations of arsenic exceeding the MCL.[7,8,9] The southeastern region of the state has the greatest potential for arsenic concentrations greater than or equal to 5 ppb and 10 ppb (Figure 1). There may be 41,000 people in just the counties of Merrimack, Strafford, Hillsborough, and Rockingham that are drinking water with arsenic levels above the EPA standard.[10,11]

Figure 1: Geographic distribution by ZIP code of the probability of arsenic in well water exceeding 10 ppb, as estimated by the USGS model.[9] Prepared by J. Chipman.

Despite the risks of both immediate and life-long health effects posed by arsenic in well water, testing seems not to be a top priority for those households with private wells. While there are relatively few studies of testing rates, the studies that have been performed suggest that a significant percent of households are unaware of the need for regular water quality monitoring.[12]

Among those who do test their water and find high levels of arsenic, many still do not take mitigative action, such as whole house or point of use water treatment.[13] Installation of a water treatment system is a multifaceted process that can be confusing or overwhelming for private well owners.

Most systems also require long-term upkeep and maintenance. Taken together, this situation suggests a need to better understand the barriers to well water testing and treatment and the opportunities for officials to provide meaningful and actionable information.[14]

The goals of this report, therefore, are to:

1. Describe the results of detailed **community focus groups** of community leaders and well owners in NH towns with the intent of revealing barriers to testing and treatment and receiving the communities' ideas for overcoming these barriers.

2. Report on the implementation and analysis of a **statewide survey** effort to estimate rates of well water testing and treatment for arsenic; identify factors influencing the rate of water testing and treatment; evaluate the effectiveness of a NH DES flyer in encouraging water testing; identify subpopulations that are less likely to test and treat their water; and determine the types and maintenance of water treatment systems being used.

3. Provide estimates of statewide well water arsenic **exposure and health effects**.

4. Propose **interventions** to address the major barriers to well water testing and treatment.

Each of these goals is addressed in the four major sections which follow, leading to a final section providing conclusions and recommendations.

COMMUNITY FOCUS GROUPS

We conducted focus groups with residents of New London, Barrington, Goffstown, and Londonderry. The purpose of the focus groups was to test the concepts and assumptions forming the basis of our survey questions, and to deepen our understanding of the knowledge, attitudes and behaviors of NH well users. For example, what informational or practical barriers, beyond those that we had already identified should we include in our survey? Are there other demographic factors that might be expected to correspond with treatment and testing rates? Are we capturing the most important thoughts, ideas, and experiences residents have related to awareness, testing, and treatment? Are our survey questions clear and the possible answer choices appropriate? What steps can we take to ensure that people respond to our survey? We recorded the meetings for the purpose of summarizing responses in this report.

In preparing a script for the focus groups, we consulted the documents and surveys produced by the Centers for Disease Control Private Well Initiative, the New Jersey Private Well Education Pilot Education Project, the University of Alberta Water Well Survey Report, the Water Policy and Governance Group at the University of Waterloo, the University of Minnesota Water Resources Center, as well as literature on guidelines for focus groups.

Selection of Towns

We targeted the towns of Barrington, Goffstown, and Londonderry for our focus groups because these towns have: (i) a relatively high number of private wells; (ii) regions with high arsenic levels according to USGS data; and (iii) a relatively high percentage of children among their population relative to other NH towns. In addition to the towns identified in our contract, we held a focus group in New London, NH because the health officer in this town reached out to us and expressed interest in hosting a focus group. Most New London residents obtain household water from a well and the town is known to have wells with unsafe amounts of uranium and radon.

The focus groups were held at the town offices on the following dates:

1. March 4, 2014, 6 P.M.
   Town Office, 375 Main Street, New London
   7 participants

2. March 5, 2014, 2 P.M.
   Town Office, 333 Calef Highway, Barrington, NH
   10 participants

3. March 6, 2014, 7 P.M.
   Town Office, 16 Main St., Goffstown NH
   7 participants

4. March 19, 2014, 4 P.M.
   Town Office, 268B Mammoth Road, Londonderry, NH
   7 participants

Selection of Participants

We aimed for 6-10 participants in each focus group and we recruited participation by working with the Selectboard, Town Planner or Administrator, and Health Officer of each town. We began by contacting the health officer of each town and requested the officer to relay our request to the Selectboard to host a focus group in a town meeting space. Two health officers declined to participate in recruitment, but relayed our request to the Town Administrators. The Selectboard of each town agreed to allow us to use a town meeting space. Participants were then recruited via town websites, social media, and through consultation with the health officer or town administrator. As an incentive, we provided entry into a lottery to win an iPad.

In total, thirty-one people participated in our focus groups. Among the participants were a town manager, a town administrator, two health officers, two building inspectors, a real estate agent, a code enforcement officer, planning board members, a director of public works, and a diverse group of residents.

Meeting Format

We scheduled ninety minutes for each focus group. We used a script to prompt and guide a discussion of issues around water testing, water test results, water treatment and sources of information. Prior to the discussion of issues we introduced ourselves, provided basic ground rules, and discussed consent forms that described the purpose of the research project, the source of funding, recording of the focus group, and voluntary participation in the focus group.

We divided our script into five sets of questions. The first set of questions focused on learning about well water usage and perceptions of well water quality. The second set addressed water testing practices, while the third concentrated on the interpretation of water testing results. The fourth set of questions focused on actions taken beyond water testing to ensure water safety and quality, including the installation and maintenance of a treatment system. The final set of questions aimed to identify sources of information. A summary of key findings follows, with details provided in our full focus group report.[15]

Summary of Findings

Well water quality

- Participants associated well water quality with taste, smell, and appearance, and many felt that high amounts of one or two contaminants did not reduce the overall quality of the water.
- Many participants used well water as their primary source of water, and several noted its superior taste and clarity.
- In contrast, a few participants preferred to drink bottled water because their well water had an atypical odor or taste.
- Many participants felt that it was common knowledge that geology and aquifers affected well water quality; however, the discussions revealed that few participants could accurately explain what influences well water and aquifers, and very few correctly identified geological variability as a factor.

- Participants in each of the four groups commented that community members that did not have a well as a child have a particularly difficult time recognizing that they are responsible for their water quality, and they are less likely to understand that the water comes from an aquifer.
- Participants felt that information about local geology and its influence on water quality was not readily available.

Well water testing

- Participants disagreed as to whether water testing was a common practice in their community; however, few participants had any knowledge of local, state, or federal water testing recommendations and participants agreed that few community members would know that they should regularly test their water.
- A majority of participants recalled testing their water during a real estate transaction, but many had not tested since that time.
- Several participants that lived in the same home for a long period of time had not tested their water since they moved in their home; for instance, one participant had not tested her water for thirty-four years because it always tasted and looked good.
- Participants that had tested their water did so because of an abnormal taste or smell, to ensure its safety because of a nearby source of contamination, or because their real estate agent or home inspector told them to; one person mentioned they tested because they heard a news story about PCBs and MtBE
- Participants identified awareness, cost and inconvenience as the major barriers to regular water testing.
- Each of the four groups commented that a locally-sponsored educational campaign would prompt many people to test their water; participants from each group also mentioned that town websites and offices would be ideal locations for more information.

Well water test results

- Most participants found it difficult to decide what parameters to test for; many relied entirely on a professional: participants mentioned well drillers, home inspectors, the town building inspector, or real estate agents; one group mentioned OneStop as a reliable source of information.
- Participants disagreed over whether water test results were easy to interpret; many mentioned that private laboratories presented information graphically, and in ranges, but others questioned the reliability of private companies; a few participants did not trust private labs because of their motivation to sell other services and products; some participants were wary of the discrepancies in costs of testing.
- Participants mentioned that they could search the internet to determine whether their results were acceptable; other stated the results provide enough information about health effects.

Well water treatment

- Among participants that had water treatment systems, the primary reason for installing a water treatment system was to address aesthetic issues.
- All participants with a treatment system commented that it was costly and onerous to maintain.
- None of the participants with a treatment system had tested their water after their system was installed.
- Cost deterred participants from treating their water.
- Participants agreed that choosing a treatment system was a complicated process and most participants relied on an expert; participants found it difficult to filter information about treatment systems on the internet.
- Several participants expressed frustration over the lack of recommendations for vendors and treatment systems; others received different quotes for the same treatment system; two groups commented that a rating system or certification process for vendors and treatment systems would be highly beneficial for consumers.
- Participants were not sure if quality was sacrificed when choosing less expensive models, and the menu of treatment options made it difficult to select a model.

Sources of information

- Overall, participants felt their communities could benefit from more information about local geology and aquifers, the potential health effects of contaminated water, and specific information about local laboratories and how to take a water sample.
- Many participants mentioned that the NH Department of Environmental Services or "the State" was the best place to go for information.
- Some participants felt that general information was accessible, but requested further information about local conditions; two groups suggested that information about other tests in the neighborhood and contamination in specific neighborhoods would be highly beneficial.
- A code enforcement officer suggested all of the issues around wells would be eliminated if there were a database of every well in the state so that well owners and public health professionals could track information about the history of each well.
- Each group suggested that their town websites would be the best place for information about water testing recommendations.
- Two groups suggested that information about water testing should be provided to residents with the tax bill.

STATEWIDE SURVEY

We created a custom survey instrument in April, 2014, with the aims of: estimating rates of well water testing and treatment for arsenic; identifying factors determining the rate of water testing and treatment; evaluating the effectiveness of a NH DES flyer in encouraging water testing; identifying subpopulations that are less likely to test and treat their water; and determining the types and maintenance of water treatment systems being used.

In preparing the survey instrument, we consulted surveys produced by the Centers for Disease Control Private Well Initiative, the New Jersey Private Well Education Pilot Education Project, the University of Alberta Water Well Survey Report, the Water Policy and Governance Group at the University of Waterloo, the University of Minnesota Water Resources Center, as well as literature on guidelines for surveys. We also used the results of our focus groups and consulted with our Project Advisory Team and the Technical Advisory Committee.

We implemented the final survey online in SurveyMonkey. We also created a postcard (Appendix A) with a link to the survey and a cover letter (Appendix B) to appear on the first page of the survey site. Depending on the respondents' answers to questions concerning testing and treatment, the survey contained between 31 and 40 questions.

Selection of Respondents

We invited the participation of four groups of private well users in NH:

1. <u>5,800 randomly selected addresses from a list of 49,866 addresses with wells</u>: The NH DES provided Dartmouth with a list of more than 60,000 wells drilled since 1984. The list was created from reports filled out by licensed well drillers in NH and contained the name(s) of the person(s) that owned the property at the time of the report. NH Print and Mail subsequently removed duplicates and undeliverable addresses, leaving 49,866 addresses from which 5,800 were selected. The residents of these addresses were directed to the website: https://www.surveymonkey.com/s/nhwells.

   We mailed 4,000 postcards on May 23, 2014. 31 postcards were returned to Dartmouth as undeliverable. We removed those addresses and mailed 3,969 reminders on June 11, 2014.

   We selected 1,800 new addresses and mailed postcards to those addresses on June 13, 2014.

   As of July 15, 2014, a total of **171 surveys** had been completed, yielding a response rate of 3%.

2. <u>1,471 addresses that received a NH DES flyer on well water testing</u>: The NH DES provided Dartmouth with a list of 2,576 addresses that received a flyer since 2011. NH Print and Mail subsequently removed duplicates and undeliverable addresses, leaving 1,471 addresses. The residents of these addresses were directed to the website: https://www.surveymonkey.com/s/nhwater.

We mailed 1,471 postcards on May 22, 2014. 116 postcards were returned to Dartmouth as undeliverable. We removed those addresses from the list and mailed 1,355 reminders on June 9, 2014.

As of July 15, 2014, a total of **48 surveys** had been completed, also yielding a response rate of 3%.

3. General public NH residents with a well. In addition to releasing press releases in conjunction with the NH DES and Dartmouth study that contained a link to the survey, we printed 500 postcards on May 22, 2014 to distribute to town offices in towns with relatively high numbers of wells. We requested that the cards be left in a place where town residents frequently pass. We also advertised the survey through a listserv of health officers, conservation commissioners, and through contacting several town officials individually. We printed 500 more postcards on June 16, 2014 for distribution. These press releases, emails, and postcards all contained a link to: https://www.surveymonkey.com/s/nhwellsurvey.

    As of July 15, 2014, a total of **550 surveys** had been completed. As the number of postcards distributed to customers is unknown, the response rate cannot be determined.

4. Individuals testing their well water during May-August 2014 at a public or private lab in NH. On May 22, 2014, we printed 750 postcards that included the URL: https://www.surveymonkey.com/s/nhtest. We sent the postcards to the NH DHHS Public Health (PH) Lab and to private labs to distribute these to lab customers. The DHHS PH Lab and five private labs agreed to mail the postcard along with water test results, and two private labs agreed to send the electronic version of the postcard in an email with the water test results. On June 16, 2014, we printed 400 more postcards and distributed them to the NH DHHS PH Lab and private labs.

    As of July 15, 2014, a total of **56 surveys** had been completed. As the number of postcards distributed to customers is unknown, the response rate cannot be determined.

Timing of Survey Responses

The following four bar charts show the number of surveys completed each week for each of the four groups. The positive impact of our reminder postcards mailed the week of June 9 to the first two groups is clearly evident, as is the impact of our selection of 1,800 new addresses from the first group on June 13. The number of responses received from the general public can be seen to diminish with time after the initial media coverage.

Randomly selected wells ('No Flyer')
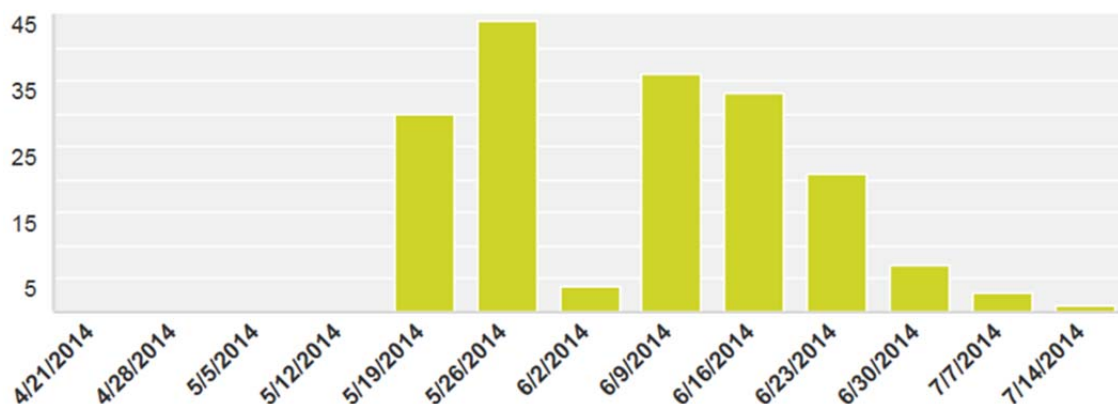
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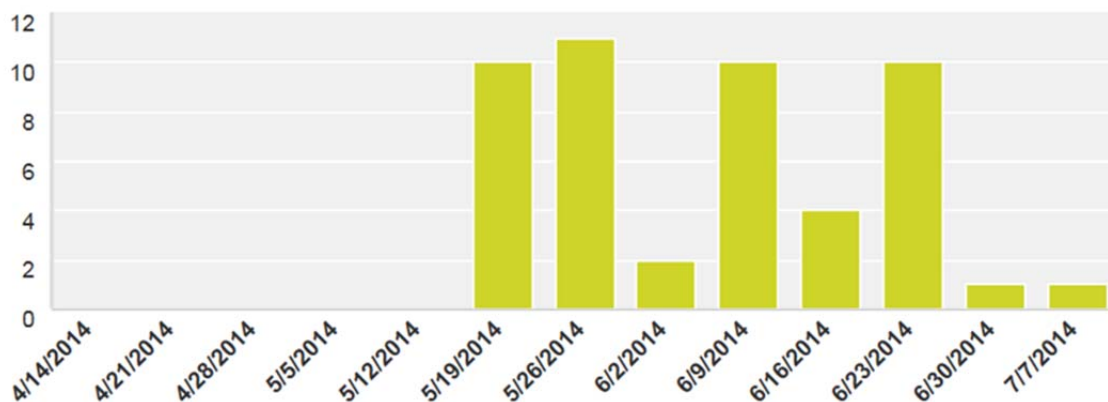
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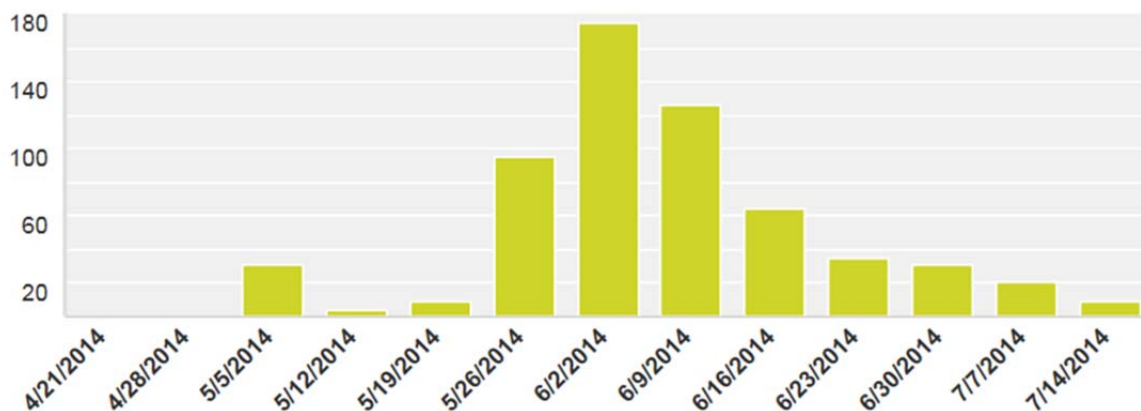
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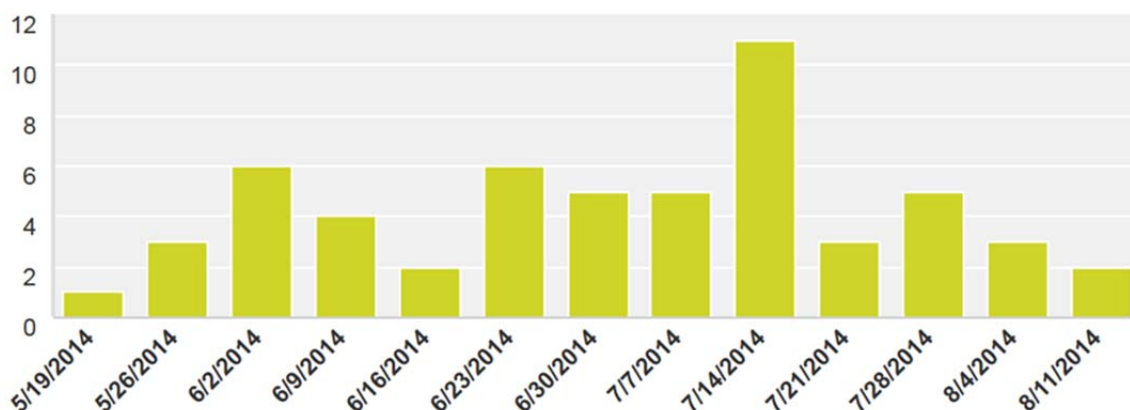
Comparison of Survey Samples

We compared responses received across the first three survey populations (not including laboratory customers) for some key questions regarding testing and treatment, as well as demographics. The results (Table1) show that the main significant differences are those that would be expected based on the selection of the populations. In particular, the population that was targeted for having received an NH DES flyer actually does recall receiving a flyer at a greater frequency. This population also reports a higher rate of testing for arsenic. This could be consistent with the receipt of a flyer – a hypothesis that will be tested by our statistical analysis. The 'flyer population' also has a lower frequency of having lived in their current location (and in NH) for more than 10 years – a fact consistent with the fact that flyers have only been distributed to owners of wells drilled since 2011. This fact may also be the reason why a smaller percentage of this population is 'not at all likely' to move in the next year. The populations do not differ significantly in any other demographic factor, such as household size, gender, age, race, education, employment, or income.

		No Flyer	SE	Flyer	SE	Public	SE	Notes:
testing and treatment	recall receiving a flyer (Q7)	▼ 21.1%	3.1%	▲ 33.3%	6.8%	▼ 25.7%	1.9%	
	have tested their water (Q8)	84.3%	2.8%	87.5%	4.8%	80.0%	1.7%	
	have tested for arsenic (Q10), conditional	▼ 65.9%	3.9%	▲ 75.6%	3.5%	▼ 61.4%	2.4%	Conditional on having tested
	have tested for arsenic (Q10), marginal	▬ 51.4%	3.8%	▲ 64.6%	3.7%	▼ 43.3%	2.2%	Overall
	concerned about arsenic test results (Q13), conditional	20.5%	3.4%	25.6%	6.7%	28.3%	2.2%	Conditional on having tested
	concerned about arsenic test results (Q13), marginal	15.2%	2.7%	20.8%	5.9%	17.3%	1.6%	Overall
	do not treat their water before drinking it (Q20)	29.1%	3.5%	31.1%	6.7%	34.7%	2.1%	
	are treating their water for arsenic (Q22), conditional	41.0%	4.5%	35.5%	8.3%	43.7%	3.7%	Conditional on having tested
	are treating their water for arsenic (Q22), marginal	25.9%	3.4%	22.9%	6.1%	22.7%	1.8%	Overall
demographics	live in a single-family residence (Q25)	96.2%	1.5%	95.7%	2.9%	93.0%	1.1%	
	own their residence (Q28)	98.7%	0.9%	100.0%	0.0%	97.1%	0.7%	
	lived in current location for more than 10 years (Q29)	▲ 55.6%	3.8%	▼ 31.1%	6.7%	▲ 63.2%	2.1%	
	resident of NH for more than 10 years (Q30)	▲ 77.5%	3.2%	▼ 58.7%	7.1%	▲ 84.8%	1.6%	
	had a well at their previous residence (Q31)	28.9%	3.5%	43.5%	7.2%	39.0%	2.1%	
	had a well at their childhood home (Q32)	29.4%	3.5%	34.8%	6.9%	30.6%	2.0%	
	are 'not at all likely' to move in the next year (Q33)	▼ 81.9%	2.9%	▲ 95.7%	2.9%	▼ 82.8%	1.6%	
	average household size (Q34)	3.0		2.9		2.8		
	no children in the household (Q35)	61.6%	3.7%	64.0%	6.9%	65.6%	2.1%	
	male (Q36)	55.6%	3.8%	54.4%	7.2%	47.9%	2.2%	
	average age of respondents (Q37)	54.4 years		51.8 years		55.6 years		
	White/Caucasian (Q38)	96.2%	1.5%	97.8%	2.1%	98.2%	0.6%	
	at least a college degree (Q39)	79.1%	3.1%	69.6%	6.6%	72.2%	1.9%	
	employed full time (Q40)	47.7%	3.8%	56.5%	7.2%	57.6%	2.2%	
	retired (Q40)	19.4%	3.0%	17.4%	5.5%	23.2%	1.8%	
	annual income of more than $100,000/yr (Q41)	33.1%	3.6%	37.0%	7.0%	33.3%	2.1%	

Table 1: Percentages of affirmative answers to selected questions and estimated standard errors (SE) among the surveys received from the first three of our sampled populations. The values given in colored cells are statistically different from the "No Flyer" sample, with direction indicated by the colored arrows.

Summary Statistics

In this section, we review some key summary statistics of the survey responses. Because of the scarcity of significant differences between the three populations shown in the previous section, we combine these three populations for the purposes of this analysis.

- Responses appear to be well-distributed around the state, with a higher rate of responses in the regions with a greater number of wells and a higher probability of high arsenic concentrations (Figure 2, left).

- 82% of respondents drink their tap water "always" or "frequently" (Q4).

- The most common groups with whom respondents have had a conversation about the safety of well water are (Q6):
  - Water treatment companies (34%)
  - Friends, neighbors, or co-workers (33%)
  - Realtors (22%), home inspectors (22%)
  - State officials (16%)
  - Many respondents (20%) have not spoken with anyone about the safety of well water
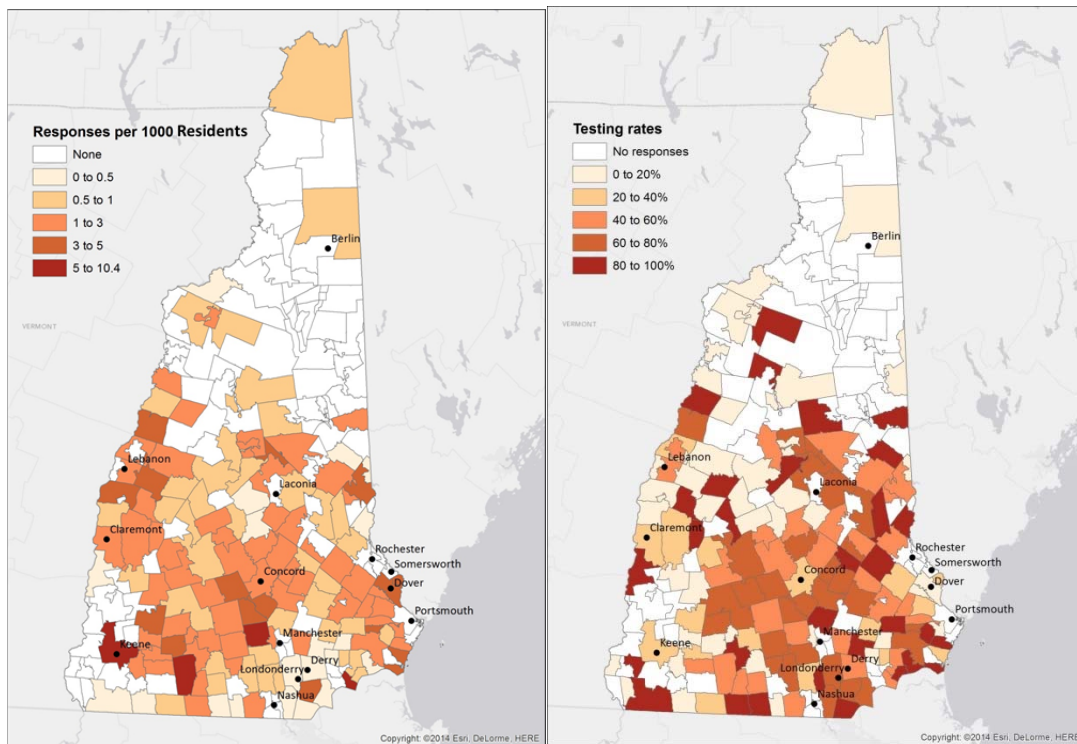
Figure 2: Geographic distribution by ZIP code of survey responses received (left) and arsenic testing rate (right). Prepared by J. Chipman.

Among the 80% of respondents who DID test their water:

- The most common time since testing is 3-10 years ago (29%) (Q9)

- The strongest considerations for testing ('very important') were (Q11):
  - I wanted to know if the water was safe to drink (77%);
  - I had it tested as part of a real estate transaction, or a real estate agent recommended it (40%);
- 65% tested for arsenic, giving an overall arsenic testing rate of 52% (Q12).

- Arsenic testing rate corresponds geographically with areas with a greater probability of high arsenic (Figure 2, right).

- The most common concerning test results were (Q13):
  - Arsenic (24%)
  - Radionuclides (19%)
  - Iron (20%)
- 74% of respondents initially understood the test results they received from the lab. Another 22% understood them after getting further help (Q14)

- 64% of respondents initially understood what actions they should take in response to the test results. Another 21% understood what actions to take after getting further help (Q16)

Among the 20% of respondents who DID NOT test their water:

- The most common reasons for not testing were (Q18):
    - I meant to have it tested but never got around to it (42%)
    - I didn't know how to go about having it tested (38%)
    - The water looks, smells, and tastes clean (33%)
    - I have not had any health problems caused by drinking the water (28%)
    - The testing costs too much (25%)
- The most common conditions which would prompt respondents to test their water were (Q19):
    - A change in the taste, smell, or appearance of the water (81%)
    - Hearing that a neighbor's water had problems (70%)
    - Hearing that other wells in town had problems (63%)
    - A coupon for a discount on a water test (61%)
    - A mobile testing lab visiting my town (60%)
    - Seeing a news article about a water quality problem in the area (59%)

Among the 67% of respondents who DO treat their water (Q20):

- The types of systems people employ include (some employ more than one):
    - Pitcher filter: 16%
    - Anion exchange: 3%
    - Aeration: 5%
    - Arsenic treatment system: 9%
    - Green sand: 2%
    - Adsorption filter: 5%
    - Water Softener: 41%
    - Iron filter: 18%
    - Sediment filter: 37%
    - Carbon filter: 15%
    - Ultraviolet (UV) disinfection: 2%
    - Radon water treatment: 10%
    - Reverse osmosis system: 12%
- 35% treat because they had the water tested and the results indicated it should be treated (Q21)
- 30% treat because the water tasted, smelled, or looked bad (Q21)
- 35% treat for a variety of other reasons (Q21)
- 39% have NEVER tested their water since starting to use their water treatment system; 21% test only RARELY (about every 5-10 years) (Q23)

Among the 33% of respondents who DO NOT treat their water (Q24):

- 46% have had their water tested and the results suggested there was no need to treat
- 16% believe a treatment system is too expensive or difficult to install, use, and maintain

Some demographic facts:
- 88% respondents live in a single-family residence (Q25)
- 91% own their residence (Q28)
- 55% have lived in their current location for more than 10 years (Q29)
- 76% have been a resident of NH for more than 10 years (Q30)
- 36% had a well at their previous residence (Q31)
- 30% had a well at their childhood home (Q32)
- 83% are 'not at all likely' to move in the next 12 months (Q33)
- The average household size is about 2.8 people (Q34)
- 65% have no children less than 18 years of age in the household (Q35)
- Respondents are equally male (50%) and female (50%) (Q36)
- The average age of respondents is 55 years, with a standard deviation of 12.5 years (Q37)
- 96% are White/Caucasian (Q38)
- 72% have at least a college degree (Q39)
- 54% are employed full time and 21% are retired (Q41)
- 33% reported an annual income of more than $100,000/yr (Q42)

Process Flow Analysis

We used our survey results to construct a diagram depicting the estimated 'flow' of surveyed well owners through the 'process' of well water testing and treatment. This type of flow diagram, in which the width of the lines is shown as proportional to the flow quantity, is referred to as a *Sankey* diagram, named after its original creator. Our Sankey diagram (Figure 3) shows that out of 1000 well owners in NH (assumed to be accurately represented by the respondents to our survey), 750 (or 75%) of them can be expected to be located in 'higher risk' towns, which we define as towns with a greater than 15% average probability of arsenic concentrations above 10 ppb. According to our survey results, of these, 440 test their water for arsenic, while 80 of the 250 well owners in lower risk towns test their water for arsenic. Of the 440 well owners from higher risk towns, 165 received test results showing levels 'of concern' to the owners, while only 5 of the 80 well owners from lower risk towns were concerned by their test results. Of the total 170 well owners with concerning arsenic levels, 115 installed a treatment system with the intent of removing arsenic (along with 50 of those well owners without arsenic levels of concern and 100 who never tested for arsenic). Based on the types of treatment systems reported, only 145 (90+25+30) of these 270 who believe they are treating for arsenic actually have an arsenic treatment system in place, while 120 (10+65+45) of the 395 who have a treatment system for other purposes are also treating for arsenic (65 unnecessarily so, based on negative prior test results). All of this implies that 520 of the original 1000 well owners are known to be 'safe' from arsenic exposure (either because they are treating for it or because their test results show that it is not a concern), while 70 well owners know that have concerning levels of arsenic but are not treating for it. An additional 410 well owners are not treating for arsenic and do not know if it is present in their water, because they have never tested for it.
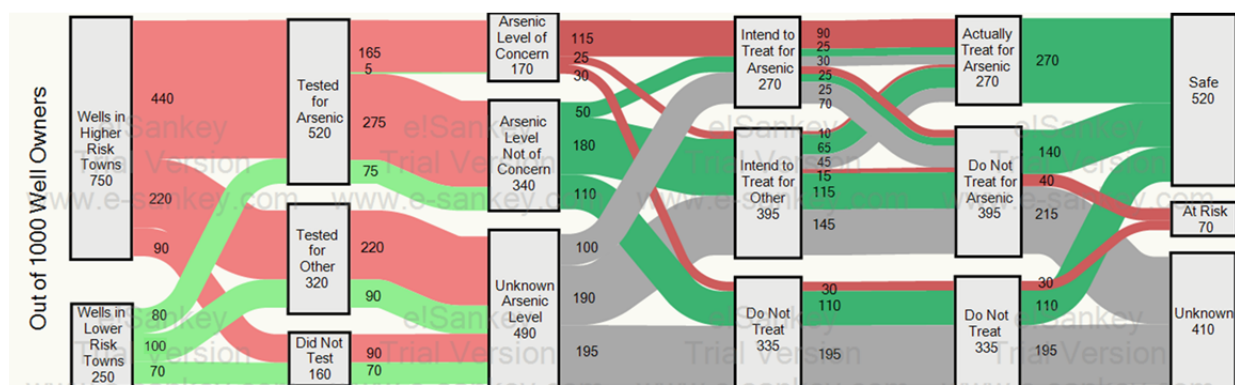
Figure 3: Sankey diagram showing the estimated flow of well owners through the multi-stage process of well water testing and treatment. Boxes represent possible states corresponding to various possible survey responses, with the number of well owners in each state (out of a hypothetical 1000 survey respondents) indicated within each box. Flows between states were derived from cross tabulation tables of the corresponding survey responses scaled to represent 1000 total well owners. Light red and light green flow lines indicate those well owners from ZIP codes with a greater (and, respectively, less) than 15% average probability of arsenic concentrations above the MCL of 10 ppb. Dark red and dark green flow lines indicate those well owners with water test results indicating a level that was (and, respectively, was not) of concern to them. Grey flow lines represent those well owners who have not tested their water for arsenic. All values are rounded to the nearest five.

In summary, important points to be taken from the Sankey diagram are that:

- Almost 40% (165 out of 440) of well owners from higher risk arsenic towns who are having their water tested for arsenic are receiving test results that are 'concerning' to them.
- Less than 10% (5 out of 80) of well owners from lower risk arsenic towns who are having their water tested for arsenic are receiving 'concerning' test results.
- About 40% (310 out of 750) of well owners from higher risk arsenic towns have not tested their water for arsenic.
- Only about half (145 out of 270) of the respondents who treat their water and state that their intent is to remove arsenic actually have treatment systems that are effective at arsenic removal. However, most of those who are correctly treating (90 out of 145) are those who received concerning arsenic test results. Most of those who are incorrectly treating their water are those who have not had their water tested for arsenic.
- Numerically, the number of respondents who are incorrectly treating their water (120) is larger than the number who have found high levels of arsenic in their water but are not treating it (70) and comparable to the number who have not tested their water but might be expected to have high levels of arsenic (about 135).

CART Analysis

To use our survey results to identify the factors associated with the rates of well water testing and treatment, we use a Classification and Regression Tree (CART) algorithm.[16] The CART algorithm searches over possible dichotomous splits of the possible predictive factors so as to find those that divide the response variable (in this case the testing or treatment rates) into distinct groups that are each as homogeneous as possible. This splitting process then continues sequentially on each of the resulting groups until a specified stopping criterion is eventually met (e.g., a minimum number of observations remaining).

CART models are advantageous because they do not require the modeled variables to follow any specific type of distribution, nor do they assume linearity in the relationships. Variables can be categorical, interval-valued, continuous, or any combination thereof. The sequential nature of splits captures underlying nonlinear relationships as well as interactions between variables.

CART models are also easy to interpret and apply. The results are represented as (inverted) trees, with all observations present at the (top) root node. The first split then divides the observations into two groups according to a condition statistically determined to be most discriminating in relation to the response variable. Subsequent splits are then shown for each of these two newly formed groups of observations and may employ different variables on the left and right sides. This process of conditional splitting continues until the stopping criterion is met, and then the average or most likely value of the response variable is reported at the endpoint (or leaf) of each final branch. When the response variable belongs to a category or class (as would be the case for a "test / no test" survey response, for example), the reported value is the frequency, or rate, of that variable.

Figure 4 shows the CART model fit to our survey data on well water arsenic testing. In this tree, 'arsenic testing rate' is the response variable and all the potential influence factors included on the survey were considered as predictor variables. Not all candidate predictor variables end up in the final tree – only those determined by the CART algorithm to be powerful predictors of testing rate. This tree shows that there are 686 total observations (from the first three survey populations) with an overall testing rate of 51.7% (shown at the top of the tree). The first split determined by the CART algorithm involves the USGS-estimated mean high arsenic (>10 ppb) probability for the town in which the survey respondent resides. This split sends surveys from low probability towns to the left and surveys from high probability towns to the right. (It is important to note that the optimal threshold value of 14% for this probability is determined by the algorithm.) Looking at the left (low arsenic) branch first, we see that the testing rate of this subpopulation of 152 respondents next depends on the income level of the household, with low income households proceeding to the left and high income households to the right. Splits continue for the low income group according to the maximum probability of high arsenic levels in the town of the respondent. At the endpoints of the branches, the test rates are shown as well as the actual number of respondents who report having tested for arsenic out of the total number of respondents fulfilling the criteria leading to that branch.
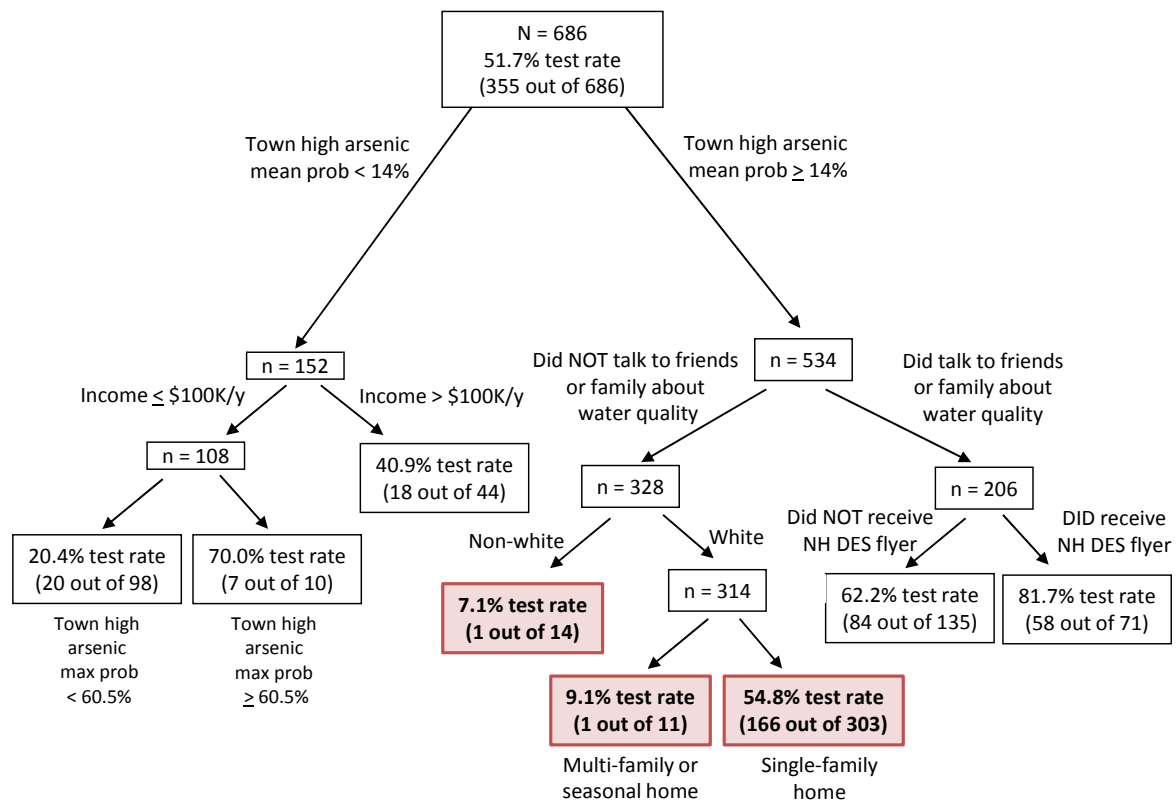
Figure 4: CART model showing the variables most accurately predicting the arsenic test rate among survey respondents. Arrow length is proportional to the amount of variation in the test rate explained by the corresponding predictor variables. Bold red boxes indicate subpopulations of concern, defined by a combination of high arsenic risk and low test rate.

On the right (high arsenic) branch, 534 observations remain. The CART algorithm determined that having talked to friends or family about water quality is the next important splitting variable. 328 respondents indicated NOT having talked to friends or family about this issue and, of these, non-white respondents show a very low test rate of only 7.1%. The test rate of white respondents in this category then depends on whether they live in a multi-family or seasonal home or a single family home, with test rates of 9.1% and 54.8% respectively. We interpret all three of these subpopulations (shown as red boxes in Figure 4), to be target populations because of a combination of being in a town with a higher probability of high arsenic concentration and a low test rate.

Additionally, in the tree shown in Figure 4, 'receipt of the NH DES flyer' shows up on the right as an important discriminating variable among a subpopulation of 206 respondents, and comparison of the testing rates between the two final leaves (58/71, or 81.7% with flyer vs. 84/135, or 62.2%, without) provides an estimate of the effectiveness of the NH DES flyer in encouraging well water testing.

Figure 5 shows a comparable CART model in which the response variable is whether or not the respondent has a treatment system intended to remove arsenic. As might be expected, having received test results that indicate arsenic levels 'of concern' is the first, best predictor of treatment.

Figure 5: CART model showing the variables most accurately predicting the rate at which respondents have a treatment system with the intent of removing arsenic. Arrow length is proportional to the amount of variation in the treatment rate explained by the corresponding predictor variables. Red boxes indicate subpopulations of concern, defined by a combination of high arsenic risk and low treatment rate.

For those who have not received arsenic test levels of concern (left branch), the treatment rate is understandably low. For those who have received test levels of concern, those who say they understand what action to take as a result of the test, are from towns with high maximum probability of high (> 10 ppb) arsenic levels, and/or have a high income (>$75K/y), treat at appropriately high rates. However, those who say they do NOT understand what action to take as a result of the test or have a lower income (<$75K/y) treat for arsenic at inappropriately low rates (41.7% and 33.3%, respectively). We identify these as target subpopulations.

Finally, we constructed a CART model predicting the rate of water 'mistreatment' – those who treat their water and state that their intent is to remove arsenic but who actually have treatment systems that are not effective at arsenic removal (Figure 6).

Here, we identify those who did not actually test their water for arsenic and who did not talk to anyone about water quality including a water treatment company as having especially high mistreatment rates. Among those who DID test their water for arsenic and found levels of concern, the mistreatment rate is highest again among those who did not talk to a water treatment company when choosing their treatment option.
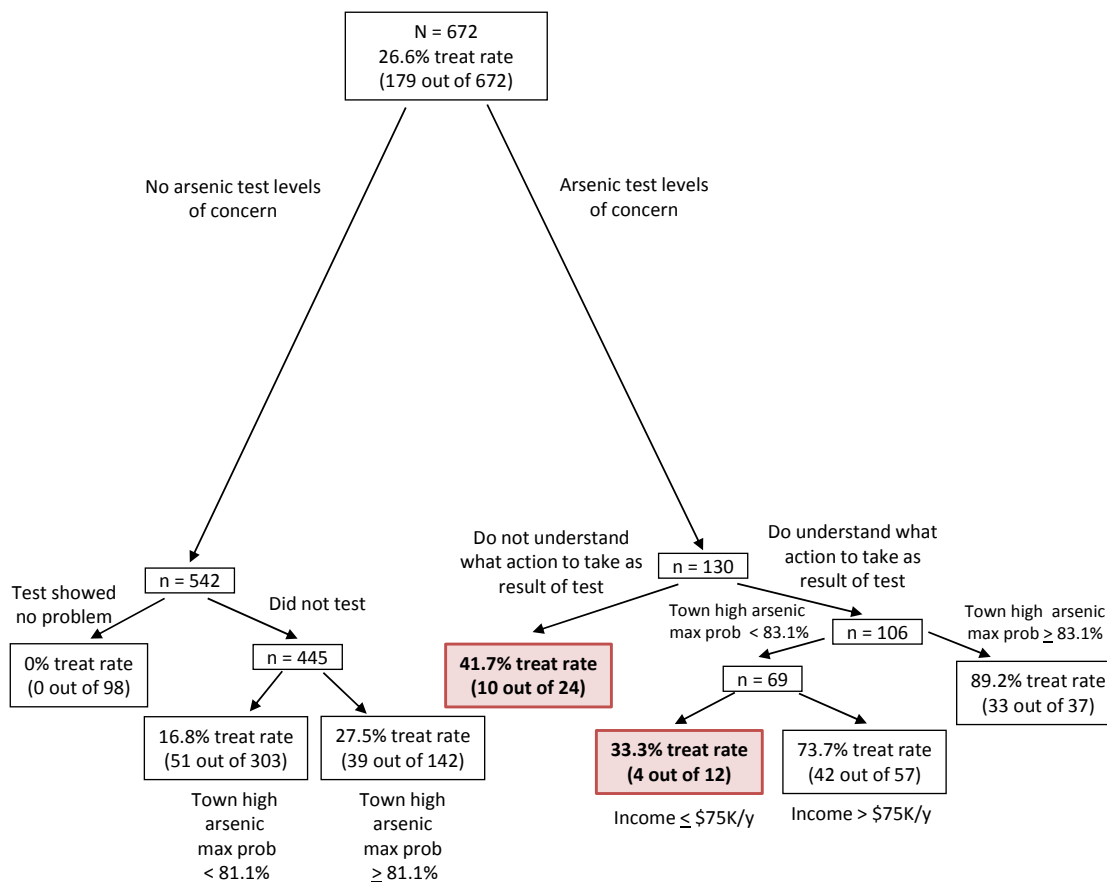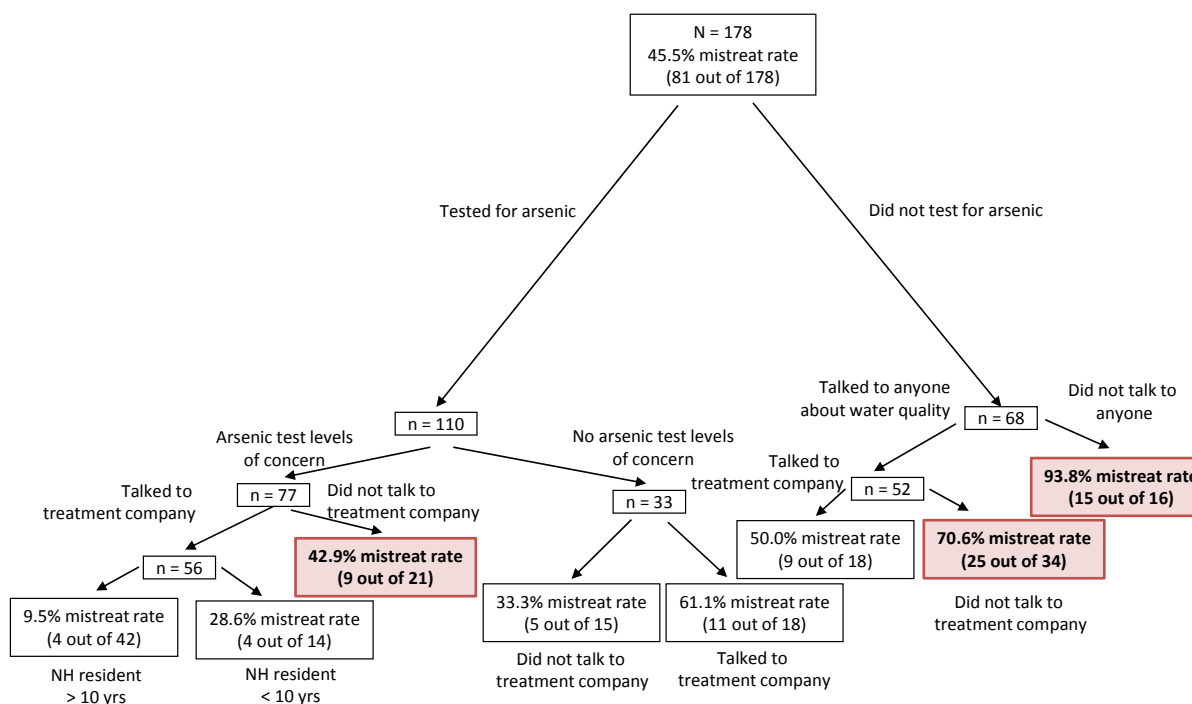

Figure 6: CART model showing the variables most accurately predicting the rate at which respondents who state that they have a treatment system with the intent of removing arsenic, but actually have reported treatment systems that are not effective at arsenic removal. Arrow length is proportional to the amount of variation in the treatment rate explained by the corresponding predictor variables. Red boxes indicate subpopulations of concern, defined by a high mistreatment rate.

From our CART analysis of survey responses, we conclude the following about target populations and associated barriers:

- Target populations for water testing include people from high arsenic towns, especially non-white residents or those in seasonal or multi-family buildings.
    - Not having talked to friends, family, or neighbors about water quality appears to be a barrier to testing. Therefore, social media or face-to-face word-of-mouth campaigns may be effective interventions to consider.
- Target populations for water treatment include residents who have received test results showing 'levels of concern', but who either do not understand or are low-income.
    - Not understanding what action to take in response to a test result and being in a low-income household may be barriers to treatment. Therefore, providing treatment information with test results and/or financial assistance may be effective interventions to consider.

- Target populations for correcting mistreatment include residents who have not performed an arsenic test, in particular those who have not previously talked to anyone about water quality, especially a water treatment company.
  - The barrier to correct treatment seems to be not having the expertise available from a water treatment expert. Therefore, encouraging re-testing and connecting people with a qualified water treatment company upon receipt of high test results are potentially effective interventions to consider.

Correction of Potential Survey Bias

Although our survey was distributed statewide, it is possible that the proportions of survey respondents who report testing their water may not be representative of the statewide rates. To attempt to correct this bias, we performed logistic regression analyses of the reported arsenic test rate against the range of demographic factors available from our survey, including type of residence, resident ownership status, duration in residence, duration in NH, household size, number of children, age, race, education level, political affiliation, employment status, income, and town-averaged USGS-estimated probability of arsenic concentration above 10 ppb. If there are any significant relations between test rates and any of these factors, we can then use the resulting statistical model, together with statewide demographic data, to generate corrected statewide testing rates.

Our analysis showed that only the town-averaged USGS-estimated probability of arsenic concentration above 10 ppb and employment status of the respondent were significant predictors of the test rate, with higher risk towns having a significantly higher test rate (p-value<0.00001) and unemployed respondents having a lower test rate (p-value=0.01). Applying the results of this logistic regression model to statewide USGS estimates of arsenic risk (Figure 1) and town unemployment data gives a **corrected statewide arsenic test rate estimate of 48%**.

A similar analysis, as applied to the arsenic treatment rate, revealed only the town-averaged USGS-estimated probability of arsenic concentration above 10 ppb to be a significant predictor (p-value=0.0001). Applying the resulting model to statewide estimates gives a **corrected statewide arsenic treatment rate estimate of 24%**.

It is important to note that if there are biases in our survey-based estimates of the testing and treatment rate that are not related to the demographic factors we included, we would not be able to correct for them using our method. In particular, if there are 'self-selection' biases resulting from some systematic difference between the people who answered our survey and the people who did not (other than the demographic factors we considered) then our rate estimates may not be fully representative. Unfortunately, we do not have a means for detecting such differences, and so we consider the rates stated above to be our best estimates at this point in time.

As a point of comparison, a 2013 survey of central Maine households (n=525) found that 59% of households reported that their well water had been tested for arsenic, but half stated that it occurred more than 5 years ago.[17] Another survey of central Maine households who were notified 3–7 years earlier that their well water contained arsenic

above 10 ppb (n= 386) found that 43% report having installed an arsenic treatment system, while 30% report taking other actions, such as drinking bottled water.[18]

Laboratory Customers

As described above, postcards inviting participation in our survey were also sent to the NH DHHS PH Lab and to private labs to distribute to customers. As of October 1, 2014, a total of 67 surveys had been completed by recent laboratory customers. This version of the survey included some additional questions pertaining to the customers' choice of lab and interpretation of the results, which we summarize here:

- 82% plan to test their water again in the future; 18% do not.
- 72% had their water tested for arsenic.
- 23% received arsenic test results that were concerning to them.
- 51% had their water tested at the NH DHHS PH Lab; 49% elsewhere (Granite State Analytical being the most common at 25% of the total).
- The most common reason people chose the lab they did was because they felt they could trust it more than other options (34%).
- 80% understood their test results, with another 17% after getting further help.
- 75% understood what actions to take in response to the test results, with another 8% after getting further help.

EXPOSURE AND HEALTH EFFECTS

In this section, we estimate the health impacts of arsenic in untreated or inadequately treated private well water in New Hampshire. We take as the basis for our analysis the series of EPA Integrated Risk Information System (IRIS) reports on the cancer risks of oral arsenic exposure. These reports are intended to synthesize the toxicological and epidemiological studies available at that time. EPA published its first IRIS assessment of inorganic arsenic in 1988, with a revision in 1998. An update to this assessment was initiated in 2003 and implemented recommendations from two National Research Council (NRC) reports (1999 and 2001). A draft of this new assessment was released in 2005 for public comment and review by the EPA Science Advisory Board (SAB). The SAB provided recommendations in 2007. In 2010, EPA released a revised draft and the SAB provided further comments in 2011. The EPA is currently working on further revisions. As the more recent EPA documents are still considered to be in DRAFT form and unable to be cited, we rely on the 1998 IRIS revised assessment[19] and the 1999 and 2001 NRC reports[20, 21], all of which are publicly available. Finally, we compare these estimates to the results of large or especially relevant subsequent studies.

Non-Melanoma Skin Cancer Risk

The 1998 IRIS assessment of arsenic health impacts focuses on non-melanoma skin cancer, which includes basal and squamous cell skin cancers. Non-melanoma skin cancers rarely spread to other parts of the body and are consequently less dangerous than melanoma, an aggressive cancer that has not been associated with arsenic. Non-melanoma skin cancers are not reported to central cancer registries, however population-based studies have estimated there to be thousands of non-melanoma skin cancers diagnosed each year in NH[22] with the number apparently increasing in recent decades.[23]

The 1998 IRIS assessment employs a linear approach for extrapolating the results of studies on high dose exposure to lower doses. Thus, each part per billion (ppb) of arsenic in drinking water is estimated to be responsible for a constant number of additional cancers (referred to as the 'unit risk'), whether overall exposure is high or low. The 1998 IRIS assessment estimates the unit lifetime risk for non-melanoma skin cancer to be 5 incidences per ppb per 100,000 people exposed.

Bladder and Lung Cancer Risk

As mentioned above, subsequent updates to the 1998 IRIS assessment initiated in 2003 have attempted to implement the recommendations of the 1999 and 2001 NRC reports. The 2001 report in particular addresses bladder and lung cancers, giving a combined unit lifetime risk estimate of 3.3 bladder and lung cancer cases per ppb per 10,000 people (Table 2). For reference, based on data from 2007-2011, the average annual number of bladder cancers in NH is 437 and the average annual number of lung and bronchus cancers is 1,031.[24]

Arsenic Concentration (μg/L)	Bladder Cancer		Lung Cancer	
	Females	Males	Females	Males
3	4	7	5	4
5	6	11	9	7
10	12	23	18	14
20	24	45	36	27

Table 2. Estimates of excess lifetime risk (incidence per 10,000 people) of lung and bladder cancer for U.S. populations exposed to various concentrations of arsenic in drinking water.[21]

Exposure Modeling Approach

Based on: the number of people served by private wells in NH; data from the USGS regarding the distribution of arsenic levels in well water; and results of our survey[25] on well water use, testing, and treatment, we can estimate the statewide total number of bladder, lung, and non-melanoma skin cancer incidences related to arsenic in private wells. We can also estimate the number of such incidences that could be avoided through effective well water arsenic removal systems.

We start with the fact that New Hampshire's population as of 2013 is approximately 1.3 million. Approximately 46% of these residents obtain their water from private wells[26], of which 90% are bedrock wells[27] (as opposed to dug wells; the water in dug wells is unlikely to contain arsenic as it has not been in contact with arsenic bearing rocks.) Thus, approximately 538,200 residents are obtaining their water from bedrock wells potentially containing arsenic.

To represent the distribution of arsenic concentrations in these bedrock wells, we use a Gamma distribution derived from the combined results of three studies summarized in a 2012 USGS report (Table 3).[28] This Gamma distribution has a mean of 7 ppb and a standard deviation of 15. In addition to representing the summary data shown in Table 3, it also provides a good fit to the subset of the SENH PRW data collected in 2012-2013 that are publicly available[29], except for some slight underrepresentation of the probability of the highest arsenic concentrations (Figure 7). This underrepresentation might be expected given that these data were collected in a high arsenic region of the state.

			Percentage of wells with arsenic greater than or equal to (ppb)		
Data source	Type of data	Number of samples	1	5	10
NHDES PSW	Non-random	954	78	37	23
NIH NEBCS	Population random	399	50	28	18
SENH PRW	Geographic random	352	59	33	21
This study (Gamma dist.)	--	--	50	30	20

Table 3. Summary statistics for arsenic concentrations in groundwater from bedrock wells in New Hampshire. (NHDES, New Hampshire Department of Environmental Services; PSW, public-supply well; NIH, National Institutes of Health; NEBCS, New England Bladder Cancer Study; SENH, Southeast New Hampshire; PRW, private wells)

Based on our survey results, we estimate that 82% of people drink their tap water 'always' or 'frequently'. We also estimate that approximately 24% of people are already treating for arsenic. As stated earlier, these survey-based estimates may be subject to bias, but are currently our best estimates available. Thus, we estimate that approximately 312,156 people are regularly drinking untreated water from a private bedrock well.

Figure 7. Distribution of well water arsenic concentrations measured in southeastern NH[29] compared to the Gamma distribution used in this study. Exceedance frequency is defined as the proportion of wells with an arsenic concentration greater than the indicated value.

Next, using our selected Gamma distribution, we can estimate not only the proportion of wells exceeding any given arsenic concentration, but also the average arsenic concentration of wells in that proportion. These estimates also compare favorably against the data from southeastern NH (Table 4). While there are certainly arsenic concentrations both higher and lower than the averages given in Table 4, under the linear model assumed by the 1998 IRIS report, the population impacts are appropriately estimated using the average exposure level.
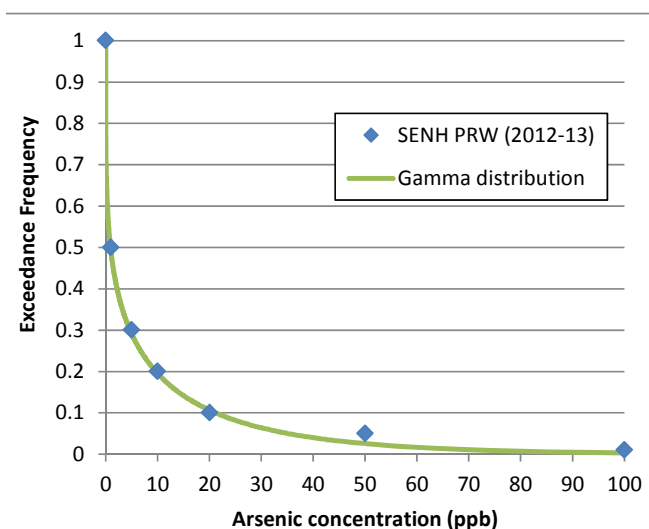
	Average arsenic concentration (ppb) of wells with arsenic greater than or equal to (ppb)						
Data source	All	1	5	10	20	50	100
SENH PRW (2012-13)	6.7	11.7	21.3	27.8	41.4	90.7	140
This study (Gamma dist.)	7.0	14.1	22.1	29.3	41.7	73.9	130

Table 4. A comparison of the conditional mean arsenic concentrations between data measured in southeastern NH compared to the Gamma distribution used in this study.

Finally, summing the unit risk values given above for bladder, lung, and non-melanoma skin cancers gives a combined unit risk estimate of 38 incidences per ppb per 100,000 people (or 0.00038 per ppb). **Applying this value to the full population of untreated private bedrock well water drinkers exposed to an average arsenic concentration of 7 ppb (Table 4), yields an estimated 830 lifetime incidences of bladder, lung, and non-melanoma skin cancers**. Comparable estimates can be derived for other

arsenic concentration threshold levels, as can as the number of cancer incidences that could be avoided by widespread water treatment that reduced well water concentrations down to the threshold level (Table 5).

Arsenic greater than or equal to (ppb)	Estimated Percentage of Bedrock Wells	Estimated Population Served	Estimated Population Drinking Water (82%)	Estimated Population Drinking Untreated Water (76%)	Estimated Average Arsenic Level (ppb)	Estimated Cancer Cases (0.00038 per ppb)	Estimated Cancer Cases Avoidable by Water Treatment
0	100	538,200	441,324	312,156	7	830	830
1	50	269,100	220,662	156,078	14	830	771
5	30	161,460	132,397	93,647	22	783	605
10	20	107,640	88,265	62,431	29	688	451
20	10	53,820	44,132	31,216	42	498	261
50	5	26,910	22,066	15,608	74	439	142
100	1	5,382	4,413	3,122	130	154	36

Table 5. Estimates of the number of bladder, lung, and non-melanoma skin cancer cases related to arsenic in private well water exceeding a range of threshold concentrations. The seventh column indicates the total number of cases, and the last column indicates the number that would be avoided by water treatment that reduced all well concentrations to the threshold level indicated in the leftmost column. Percentages of wells exceeding the thresholds and estimated average arsenic concentrations are estimated from a Gamma distribution with mean of 7 ppb and standard deviation of 15 ppb.

For example, we estimate that there are 688 cancer cases among those residents with arsenic concentrations greater than the MCL of 10 ppb, and that **if the water from such wells could be treated to a level of 10 ppb, 451 bladder, lung, and non-melanoma skin cancers could be avoided.** Figure 8 shows the relation between the arsenic 'action level' and the number of potentially avoided cancer cases, highlighting the fact that the majority of avoidable cancers would be achieved by well owners acting on the 10 ppb MCL level.
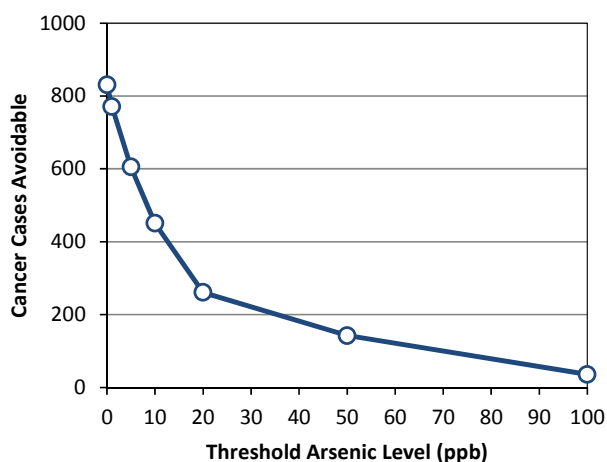

Figure 8. The estimated number of bladder, lung, and non-melanoma skin cancers avoidable by removing arsenic from well water down to a range of threshold levels from 0 to 100 ppb.

Additional Evidence

Quantitative studies subsequent to 1998 IRIS assessment and its updates range from those of only indirect applicability conducted on populations that are culturally and genetically dissimilar from the population in NH, to those of direct relevance conducted here in the state under actual exposure conditions. Unfortunately, given the sample sizes and exposure levels involved, the level of precision of these various studies happens to be approximately inversely proportional to their relevance to the situation in NH (Figure 9).
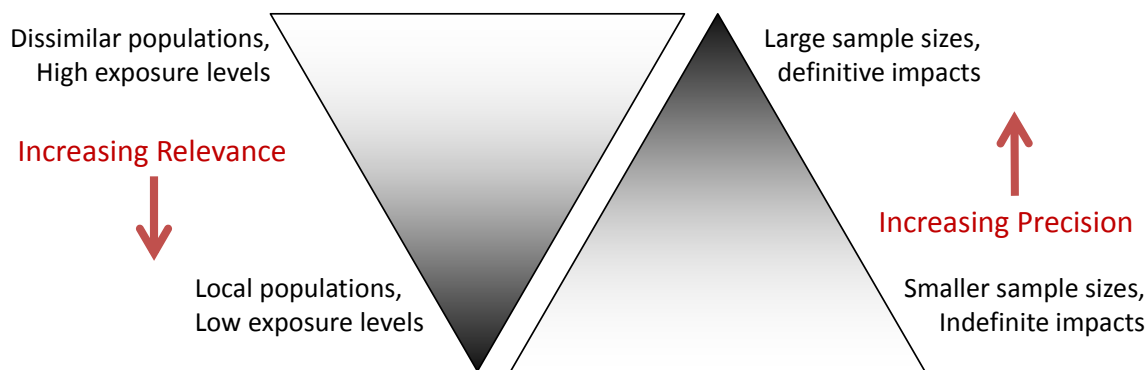

Figure 9. Schematic illustrating the tradeoff between relevance and precision in the available studies of the health impacts of arsenic exposure.

In the next subsections, we review two sets of studies which span the range of conditions presented in Figure 9, from a large population in Bangladesh subject to high exposure levels to smaller local populations in New England subject to lower exposure levels.

HEALS Data for Populations in Bangladesh

The Health Effects of Arsenic Longitudinal Study (HEALS) in Bangladesh followed over 2,000 people with elevated drinking water arsenic and compared them to people with negligible arsenic over roughly 7 years.[30] Results suggest that arsenic exposure at a level comparable to that in NH wells is associated with an elevated incidence of many adverse health effects. In particular, HEALS suggests a hazard ratio of 1.34 [95% confidence interval (CI) 0.99-1.82] for all-cause mortality in people exposed to 10-50 pbb arsenic compared to 0.1-10 ppb arsenic. Given the assumptions outlined above, this implies that of the 62,431 people exposed to 10 ppb arsenic or higher in NH, the annual death rate would increase from 1 in 78 (based on the average lifespan) to 1.34 in 78. This translates to approximately 272 additional deaths *per year*. Of course, this is a simplification that assumes the distribution of arsenic exposure levels among NH residents with well water containing greater than 10 ppb arsenic is comparable to that of Bangladeshis exposed to arsenic in the 10-50 ppb range. It also assumes that the two populations are comparable in other risk factors such as diet, smoking, and genetic predisposition to various diseases. It is unclear whether the risk estimate for NH would be higher or lower if these possible inconsistencies were to be resolved. Nevertheless, the HEALS study does support the hypothesis that exposure to arsenic in drinking water over long periods can increase mortality to a significant degree.

Low Dose Arsenic Studies in New England

Bladder and lung cancers are frequently cited as a potential consequence of chronic exposure to arsenic. The National Cancer Institute in 2010 estimated the NH bladder cancer rate at 29.7 cases per 100,000 per year [95% CI 27.0-32.6], giving it the highest rate of bladder cancer in the U.S., well above the national rate of 19.7 [95% CI 19.5-19.9].[31] While the difference cannot be attributed entirely to arsenic exposure, it is notable that the increment of ~10 per 100,000 corresponds to 130 additional bladder cancers *per year* in the state, an order of magnitude that is more similar to the HEALS than the IRIS estimates. Notably, Maine ranks second in bladder cancer incidence and also has high levels of arsenic in groundwater.

Epidemiological data from New Hampshire indicate that levels of arsenic seen in the state are consistent with increased cancer risks. Karagas et al. found an elevated odds ratio (OR) for bladder cancer in the uppermost category of arsenic exposure as determined by toenail arsenic (OR: 2.17, 95% CI: 0.92-5.11 for greater than 0.330 µg/g toenail arsenic compared to less than 0.06 µg/g) in smokers.[32] Heck et al. showed that higher arsenic exposure in New Hampshire was also associated with small-cell and squamous-cell carcinoma of the lung [OR: 2.75; 95% CI: 1.00–7.57][33].

Gilbert-Diamond et al.[34] reported a positive association in New Hampshire between recent arsenic exposure estimated by presence of arsenic in urine and squamous cell carcinoma, a form of skin cancer (OR: 1.37, 95% CI: 1.04-1.80) for each log-transformed ppb increase in urinary arsenic concentration. For this reason, we would believe that, although the NRC de-emphasized skin cancer in its 2001 report, it remains an important consideration for low dose exposure in New Hampshire.

Further studies in NH confirm elevated bladder cancer risks associated with arsenic in drinking water[35], and have found evidence of other arsenic-related adverse health effects in children[36]. Similarly, a recent epidemiological study in Maine suggests that well water arsenic levels are negatively associated with various measures of IQ and perceptual reasoning[37].

Health Effects Summary

The most recent final (1998) EPA IRIS assessment of arsenic influence on non-melanoma skin cancer risk, together with lung and bladder cancer estimates from a 2001 report of the National Research Council, suggest that treatment of water from all wells containing greater than 10 ppb arsenic could avoid roughly 451 lifetime cancer cases among the current New Hampshire population. Acting on, and treating to, a threshold level of 5 ppb is estimated to avoid an additional 154 cancer incidences. Notably, more recent research has also identified non-cancer health effects that were not included in our analysis.[37,38] This trend is consistent with the fact that, over the last 25 years the number of diseases associated with arsenic has *increased*, the locations associated with arsenic mediated disease have *increased* [39,40], and estimates of what constitutes a safe long term arsenic dose have *decreased.* [41]

For this reason, we believe that our estimate based on information available at the time of the 2001 NRC report is more likely to underestimate health effects in NH than overestimate them. This is consistent with the expectation that the current DRAFT IRIS

guidelines are likely to lead to a further increase in the estimated cancer risk rate.[42] Thus, we conclude that our estimate of 451 potentially avoidable lung, bladder, and non-melanoma skin cancer cases is likely a lower bound on a very uncertain estimate of the full health impacts of exposure to arsenic in well water in New Hampshire.

The analyses presented in the previous sections provide us with essential information to achieve the ultimate goal of reducing the risk of adverse health effects to private well owners in New Hampshire exposed to arsenic and other contaminants in untreated or inappropriately treated drinking water. Our proposed intervention strategy is designed to overcome the barriers to well testing and treatment identified in our focus groups and statewide survey. It is also intended to reach specific target populations that we identified as having particularly low testing and treatment rates or otherwise being at greater risk.

Process for Determining Interventions

We believe it is useful to classify potential interventions as operating at either the *statewide* or *local* level (Figure 10). Statewide initiatives are centrally planned and implemented by either the state government or a single subcontractor. As there is no opportunity for a control population or replicate, they are primarily designed for maximal public health improvement rather than pilot testing or statistical learning. Local interventions, on the other hand, could be planned and implemented by town offices, local health centers, or community organizations. When implemented following principles of Community Based Social Marketing (CBSM)[43,44], local efforts or partnerships have been shown to be especially successful in motivating behavioral change. With the potential for replication of interventions across multiple communities, a set of local interventions can be designed that is amenable to statistical analysis and hypothesis testing. Specific ideas for both statewide and local initiatives that follow from our focus group and survey results are presented below.
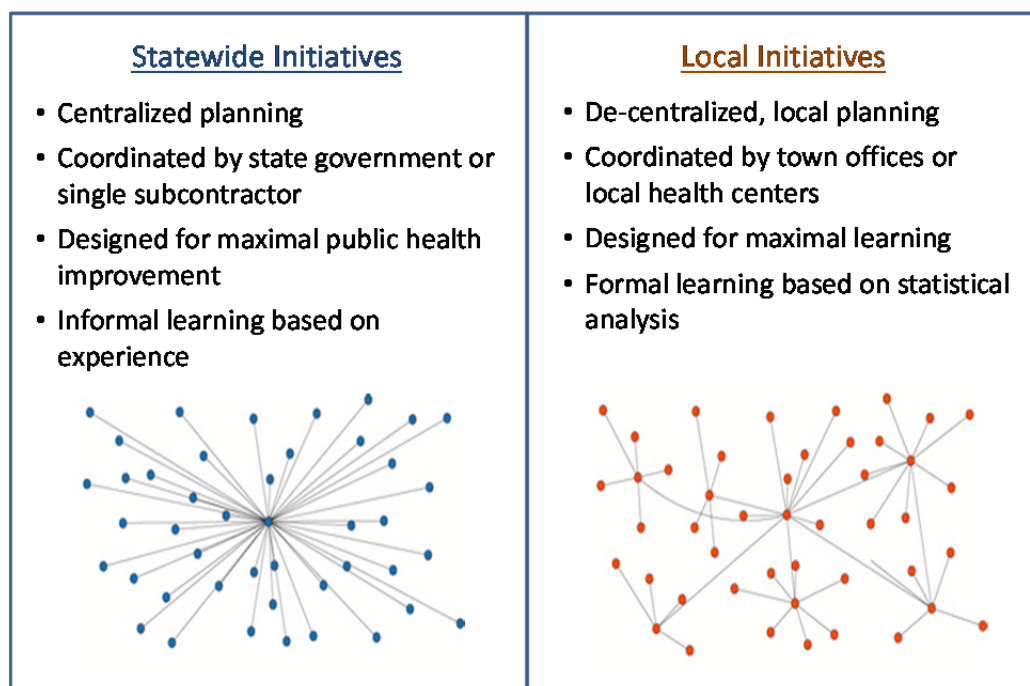

Figure 10. A comparison of some key characteristics of statewide and local health intervention initiatives.

Potential Statewide Interventions

Marketing campaign: Implementation of a professional marketing campaign based on our survey results relating to barriers to testing and treatment, in particular the need to emphasize narrative and personal experience rather than statistics or generalizations. A sub-contractor would be hired based on a competitive bidding process with the task of developing written and visual materials. For example, the effort could include a catchy slogan or image and directions to the NH Arsenic Consortium website where people could access more information on testing, interpreting, test results, choosing a treatment system, etc. A particular appeal will be made to well owners who have tested in the distant past but have not tested again or who may think they are treating their water but are not removing arsenic.

Discount program: Fully subsidized or significantly reduced cost testing through DHHS PH Lab and participating NH-certified labs, especially if residents have never tested, or have not tested in more than five years. A model developed by the URI Cooperative Extension System[45], solicits accredited labs to provide services at a discounted rate, in return for being able to provide publicity information (name, phone and URL) on the mailing sending out the coupon, have a link to lab websites from the NH Arsenic Consortium website, and receive a copy of the outcome report. All well owners who utilize the coupon would receive information with their test results on treatment options if they had detectable levels of arsenic, and would receive an invitation to a private well owner workshop. An appeal to well owners to test their treated water should also be included.

Social media: Aggressive online social media campaign targeting younger families with children. This would involve twitter hashtag development and use of twitter to direct well owners to the NH Arsenic Consortium website or Facebook page. Vine videos would be utilized for children in grades 5-12 to report to their families. A subcontractor would be hired to produce an overall design that increases target audience conversations and connections using digital technology.

Purchase/lease agreements: Work with banks, realtors, and landlords to incorporate arsenic testing into purchase and lease contracts. This could include required testing for Section 8 vouchers, welfare assistance or those who have state or federal subsidies/grant or loans for development of housing units. This would likely involve organizing a steering committee from state agencies and relevant stakeholders.

Online tools: Online discussion forum and mapping tool to collect and share community comments on well owner experiences relating to testing and treatment, do's and don't's, and ratings of testing and treatment companies. This could also link to the web tool being developed by NH DES as the other part of this contract and to an online mapping tool being developed by the USGS and NH EPHT program. It could also link to a tool being developed by the Children's Environmental Health and Disease Prevention Center at Dartmouth.

Product review: Work with *Consumer Reports* to establish a rating of treatment systems (both specific system types and actual vendor products) to provide the kind of recommendations that state and academia are not able to provide. This information

would be made available as a link on the NH Arsenic Consortium website and in written and digital materials including a fact sheet on arsenic treatment systems.

Potential Local Interventions

Town communications: Provide state-of-the-art communications on testing and treating private well water via town-level channels (e.g., tax bills, town meetings, listserv), utilizing network of health officers, building inspectors, and appraisers to identify effective ways to distribute information to town residents.

Testing events: Establish 'well testing days' which bring the testing kits to local residents by working through a community board (e.g., planning board, conservation commission) to establish a specific day to hand-out testing kits and deliver them to a lab on a specific date thereafter. Work with the community board to publicize the testing event and to provide follow-up information on interpretation of well testing results and remediation systems in consultation with NH DES.[46] Both written and online materials would be provided. To distinguish the effects of cost and convenience, the tests conducted through these events would not be discounted or subsidized, unlike the statewide program mentioned above.

Community networks: Utilize existing public health and community partnerships (e.g. Rockingham Community Action, Lakes Region Partnership for Public Health), regional planning commissions, and related networks of community organizations (including churches, healthy home visiting system, etc.) to distribute state-of-the-art communications in a locally effective and cost-efficient manner. Thus, these organizations would leverage existing resources and communications channels and develop and direct local interventions based on a competitive bidding process or a self-selected interview process. Criteria for interventions would be provided as well as messaging and materials as needed. The DHHS, the Community Health Institute, and the NH Public Health Association will be consulted in this process.[47]

Rental units: Meet with local landlords, vacation rental agencies, and tenants to explore the rights and responsibilities of well water testing and treatment. Help to identify cost-effective solutions and provide materials on arsenic health effects, testing, and treatment.

School programs: Connect with childcare centers and schools (through e.g., lunch programs, school nurses, science programs) with information on arsenic health effects and the need for families to test and treat their well water. Provide factsheets with links to the Children's Health and Disease Prevention Center at Dartmouth and to the NH Arsenic Consortium website. Provide training to regional representatives for childcare associations, school association and nurses associations so that they can in turn train others to provide this information more locally through presentations and one-on-one conversations. Messaging and materials (possibly including curricular materials) would be provided.

Intercept campaign: Partner with local offices or community-based organizations to intercept people at specific popular places within the community such as the transfer station, general store, local market, farmer's market, or churches to inform them about the need to test and potentially treat their private wells. Utilize staffing from a public

health contractor to train representatives from these local partner organizations to greet and inform people from a table-top or standing display which would include education and awareness materials (messaging and materials would be provided). Appropriate incentives, or giveaways, would also be included at the display—which could include coupons for well-testing discounts. One-on-one conversations would be encouraged, and actual well-owners from the community with experience testing and treating their wells would be recruited as display 'greeters.' Depending on location, coffee and donuts or other snacks could also be provided.

Description of Key Criteria

In consultation with our Project Advisory Team, we identified a set of criteria appropriate to the selection of interventions in year 2 of the project. They include the following (not necessarily in order of importance):

A. **Sustainability**: Does the intervention create long-lasting change by establishing institutional or organizational structures or a new behavioral norm, or does it only create a short-term 'blip' that fades away upon conclusion?

B. **Reliability**: Is there evidence that the intervention will be successful?

C. **Timeliness**: Can the intervention be completed within the course of the single year we have available? Is this year the right time for this initiative?

D. **Measurability**: Is it possible to develop and record metrics that measure the effectiveness of the intervention? Are baseline or control available?

E. **Scope**: Are many people likely to be positively impacted by the intervention?

F. **Visibility**: Is the initiative visible to people? Will it receive positive attention that may have beneficial effects?

G. **Reproducibility**: Is the intervention reproducible in other communities or states? Can the knowledge gained be transferred to other situations?

H. **Justice**: Is the intervention consistent with principles of environmental justice? Does it target subpopulations at disproportionate risk?

I. **Cost**: Is the one-year cost of the intervention acceptable?

Comparing Interventions against Criteria

In Tables 6 and 7, each of the proposed interventions is evaluated according to the criteria described in the previous section. We use a scoring system of 1 for 'low fulfillment", 2 for 'medium fulfillment', and 3 for 'high fulfillment' for each criterion. These are also indicated by the colors red, yellow, and green, respectively. For cost, we indicate whether the overall cost of the intervention is expected to be 'low' (<$10K), 'med' ($10-30K) or 'high' (>$30K).

From Table 6 it appears that the statewide interventions that best balance the selected criteria include a *marketing campaign*, *discount program* and the development of *online resources*. A marketing campaign, while likely to be expensive, will have a wide scope. It will also be highly visible and, if implemented carefully and professionally, could be reproducible in other times and places. We have less confidence in the ability of this initiative to promote long-term behavioral change beyond the duration of the campaign itself. A discount program would also have a wide scope. According to our

focus group and survey results, it is also likely to be effective and would address our low-income target population. By tracking water samples submitted through this program, the impacts would also be easily measureable. The development of online resources, such as a forum for exchanging information, would be timely and reproducible. By providing a permanent location where people could post updated information, it would also be sustainable. Our focus group and survey work suggests that people desire such a resource and have looked online in the past for one. The downside of this initiative is that it is unlikely to reach our target populations in a focused way.

Table 6. A comparison of proposed statewide interventions against key criteria.

	Interventions	A. Sustainability	B. Reliability	C. Timeliness	D. Measurability	E. Scope	F. Visibility	G. Reproducibility	H. Justice	I. Cost
		Criteria								
Statewide	Marketing Campaign	1	2	3	2	3	3	2	1	High
	Discount Program	1	3	3	3	3	2	2	3	High
	Social Media	2	1	2	2	1	2	2	1	Med
	Purchase/Lease Agreements	3	2	2	1	3	1	2	2	Low
	Online Resources	2	2	3	2	2	2	3	1	Med
	Product Review	2	2	3	1	2	2	1	1	Low

As local initiatives (Table 7), the use of ***town communications***, ***testing events***, and ***intercept campaigns*** appear to be the most promising overall. In our focus groups, people identified locally-organized campaigns and events as likely to be more successful than top-down, institutional efforts. Based on our own past experience and the experience of colleagues in Maine, testing events and face-to-face campaigning have proven to be an effective method, especially when led by local organizers. While town information and testing events are not aimed specifically at our target populations, the intercept campaign can be structured so that it reaches at-risk groups. We expect that much can be learned by pilot testing each of these three local interventions, both in isolation and in concert with each other.

Table 7. A comparison of proposed local interventions against key criteria.

	Interventions	A. Sustainability	B. Reliability	C. Timeliness	D. Measurability	E. Scope	F. Visibility	G. Reproducibility	H. Justice	I. Cost
Local	Town communications	2	2	3	2	2	2	3	1	Med
	Testing events	2	3	3	3	2	2	3	1	Med
	Community networks	2	2	2	2	2	2	2	2	Med
	Rental units	2	1	3	1	1	1	2	2	Low
	School program	2	2	2	1	1	2	3	2	Med
	Intercept campaign	2	3	3	2	2	3	3	2	Med

Based on this analysis of potential statewide and local intervention initiatives and input from our Project Advisory Team and the Technical Advisory Committee, during year 2 we propose to pursue the three selected local initiatives, *town communications*, *testing events*, and *intercept campaigns*. These initiatives will be implemented in six highly motivated towns according to the experimental design procedure described below.

Experimental Design of Local Initiatives

A distinct advantage of pursuing local initiatives is that they can be replicated across multiple communities, enabling statistical analysis and hypothesis testing of their relative effectiveness. This is consistent with the principles of Community-Based Social Marketing, which comprises a five-step process including:1) identification of barriers and benefits of behavior; 2) developing a strategy that uses tested tools; 3) conducting a pilot of the strategy; 4) strategy evaluation; and 5) strategy implementation. It has become clear that merely communicating facts about a risk does not ensure behavior change.[48,49] Community-based social marketing fosters behavior change through stakeholder dialogue and social marketing initiatives specifically designed to address targeted barriers, such as those identified in our analysis. For example, recruiting well owners who have tested their wells to talk to their neighbors about the low cost and availability of treatment alternatives would be a form of social marketing we are proposing as part of the intercept campaign and which is corroborated by the broader research on barriers to well testing.[50]

For implementing the pilot testing and evaluation steps, we propose a 'blocking' approach to experimental design in which a total of six towns are recruited for participation and each of three different interventions is implemented in four different towns (Table 8). If arranged correctly, this allows all combinations of every two interventions to be duplicated. In this way, all individual effect magnitudes and their interactions can be estimated. Strictly speaking, this approach requires 'random' selection and assignment of towns to the various intervention 'treatments', as well as independence of towns with respect to the effect of interventions. We will seek to meet these assumptions to the extent practically possible.

Table 8. Experimental design of the application of interventions to towns. Shading and X's indicate towns where the indicated intervention is applied.

Intervention	Town					
	1	2	3	4	5	6
A	X		X	X		X
B	X	X		X	X	
C		X	X		X	X

Based on the USGS arsenic probability maps and our survey results, we anticipate selecting communities from Rockingham/Strafford, Merrimack/Hillsborough and Belknap counties for the local pilot testing. Town selection will occur utilizing the community readiness assessment[51,52] which will help us determine the extent to which a particular community is prepared for a specific intervention. Recruitment of towns to participate in the community readiness survey will occur through direct email and phone contact via all town administrators, selectboard chairs and health officers. The existing relationships we established during year 1 of this contract will also be accessed as needed. Final selection methods and considerations will be discussed with the Technical Advisory Committee. Six to eight representatives from a cross-section of each community will be selected to participate in the readiness survey (Figure 11).
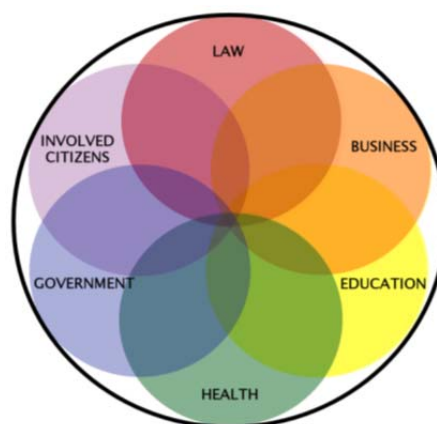

Figure 11. Possible sectors of the community to be included in the readiness survey. (From the Community Readiness Handbook[51])

Development of State-of-the-Art Communications

We plan to design improved outreach and education materials for use in all local interventions using the social marketing tool MIYO (Make It Your Own), a system developed by researchers at Washington University in St. Louis. This online tool helps users create their own versions of evidence-based health communication materials for specific populations. Users 'build' these materials by choosing from a menu of evidence-based approaches recommended by the Community Guide to Preventive Services, and then customize them by choosing from a library of images, messages, and graphic designs. MIYO users put their creations into electronic documents that can then be printed, e-mailed, texted, used online, or otherwise distributed to reach target audiences. We will also consider theories and strategies from *Water Words That Work*, a program designed to help environmental professionals create materials that effectively transfer messages and produce the desired behavior changes in the target audience.

Additionally, we plan to use a tool developed by Brian Zikmund-Fisher at the University of Michigan to develop icon arrays. Icon arrays are graphical representations of risk that have been shown to communicate risk statistics more effectively than bar or pie charts by reducing cognitive barriers and biases. Icon arrays improve not only people's understanding of the exact numbers ('verbatim' knowledge) but also their overall 'gist' understanding. This is particularly important because a better conceptual understanding leads to improved individual decision making.

All materials for the local interventions will be developed in partnership with a health literacy or health promotion specialist and will be audience tested using focus groups and phone interviews.

Details for Implementation

We will coordinate activities with the DHHS Public Health Lab when possible, and utilize their expertise for presentations and information. We will also work closely with the team of private labs that have been recruited to provide testing information to pursue the possibility of discounted testing as an incentive for private well owners. Regina Flynn, from the Cancer Prevention Program at NH DHHS has indicated she is available to provide consultation for the community readiness evaluation. As appropriate, relative to the experimental design process, we will make use of the media (e.g. newspaper, radio, online, television) to assist with conveying our messaging and information to the targeted communities. Cost, timing and implementation considerations are estimated in Table 9.

Table 9. Projected materials cost, timing and implementation considerations for Year 2.

Local Initiatives	Projected Cost	Time of year	Oversight required	Local Assistance Required	Messaging delivery
Town Communications	$5,000	Immediate	Public Health Contractor	Town officials/health officer	-Fact sheets -website
Testing Events	$1,000	Spring/ Summer	Contract w/ Health Promotion Organization	Local champion(s)	-Presentation -Fact sheets -Word of mouth -Display
Intercept Campaign	$6,000	Spring/ Summer	Contract w/ Health Promotion Organization	Private well owners Local organizations who receive training	-Word of mouth -Display -Fact sheets

A detailed timeline and work plan will be developed for the interventions we plan to pursue. However, we anticipate that the local pilot initiatives will need to be completed by May 31, 2015 allowing time for evaluation of the interventions to be completed by June 30, 2015.

CONCLUSIONS AND RECOMMENDATIONS

We recommend that as a next step the three selected local initiatives, *town communications*, *testing event*s, and *intercept campaigns*, be implemented in six highly motivated towns according to the described experimental design procedure. We believe this should be done before pursuing any statewide options. The careful and focused pilot testing of local interventions will provide a means for evaluating whether, how, and when to implement the more extensive and costly statewide initiatives. Implementing the local initiatives we recommend will also allow us to determine community "readiness" to receive the messaging materials we develop. Additionally, this information would allow us to hone in on our goals for a statewide intervention by using the information from the local initiatives to identify the desired outcomes and working backward to design the appropriate mechanisms (or combination thereof) to reach those goals. Finally, media coverage of our local efforts would further improve readiness statewide, thus increasing the likelihood of sustained behavioral change.

APPENDIX B: SURVEY COVER LETTER

Dear New Hampshire Resident:

Thank you for visiting our survey site. The Thayer School of Engineering at Dartmouth is working with the NH Department of Environmental Services and the NH Department of Health and Human Services* to investigate people's exposure to contaminants in private well water. The information from this survey will help us design effective programs that will protect public health.

To complete the survey, the water entering your home must be supplied by a private well. The person filling out the survey should be an adult, age 18 or over, who is responsible for maintaining your home's drinking water supply. You may be a renter, homeowner, or landlord (if you look after the drinking water quality for your tenants). Your individual answers will not be shared with anyone and your personally identifiable information will never be used in any presentation or report on this project.

If you complete the survey, you can choose to be entered into a drawing to win an iPad as part of our thanks to you. Please indicate at the end of the questionnaire whether you wish to be entered into this drawing and provide an email address or phone number where you can be reached if you are the winner. (While your chances of winning depend on the number of people who complete the survey and enter the drawing, we estimate the chances to be approximately 1 in 400.)

Your participation in this survey is voluntary. The survey should take approximately 15 minutes to complete. You may choose to stop the survey at any time. The study has been reviewed by the Committee for the Protection of Human Subjects at Dartmouth College. If you have any questions regarding your rights as a participant in this survey, you may contact them by telephone at 603-646-6482.

Questions regarding the survey may be directed to me, Prof. Mark Borsuk, the principal researcher, by telephone at 603-646-9944 or by e-mail at mark.borsuk@dartmouth.edu.

I hope you enjoy completing the survey, and I look forward to receiving your responses!

Many thanks,

Mark E. Borsuk, Ph.D.
Associate Professor of Engineering

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REFERENCES

[1] DeSimone, L.A., P.A. Hamilton, and R.J. Gillom, Quality of Water from Domestic Wells in Principal Aquifers of the United States, 1991-2004, in National Water-Quality Assessment Program, Circular 1332. 2009, U.S. Geological Survey. p. 1-48.

[2] Miles, J., Drinking Water Source Data Brief, N.H.E.P.H.T. Program, Editor. 2007.

[3] Naujokas, M.F., et al., The broad scope of health effects from chronic arsenic exposure: update on a worldwide public health problem. Environmental Health Perspectives, 2013. 121(3): p. 295.

[4] Anders, W.M., R. J. Bull, K. P. Cantor, D. Chakraborti, C. Chen, A. B. DeAngelo, D. M. DeMarini et al., Some drinking-water disinfectants and contaminants, including arsenic. World Health Organization, 2004. 84.

[5] ATSDR. Priority List of Hazardous Substances. October 25, 2013. Available from: http://www.atsdr.cdc.gov/spl/.

[6] USEPA. Arsenic in Drinking Water. September 17, 2013. Available from: http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/.

[7] Montgomery, D.L., et al., Arsenic Concentrations in Private Bedrock Wells in Southeastern New Hampshire, in U.S.G.S. Fact Sheet 051-03. 2003. p. 1-6.

[8] Peters, S.C., et al., Arsenic occurrence in New Hampshire drinking water. Environmental Science and Technology, 1999. 33(9): p. 1328-1333.

[9] Ayotte, J.D., et al., Estimated Probability of Arsenic in Groundwater from Bedrock Aquifers in New Hampshire, 2011. 2012. p. 25.

[10] Montgomery, D.L., et al., Arsenic Concentrations in Private Bedrock Wells in Southeastern New Hampshire, in U.S.G.S. Fact Sheet 051-03. 2003. p. 1-6.

[11] Ayotte, J.D., et al., Estimated Probability of Arsenic in Groundwater from Bedrock Aquifers in New Hampshire, 2011. 2012. p. 25.

[12] Novokowski, K., et al., Water Well Sustainability in Ontario. 2006, Ontario Ministry of the Environment.

[13] Flanagan et al. Dissemination of well water arsenic results to homeowners in Central Maine: Influences on mitigation behavior and continued risks for exposure. *Science of the Total Environment*. In press.

[14] Jones, A.Q., et al., Public perception of drinking water from private water supplies: focus group analyses. BMC Public Health, 2005. 5.

[15] Borsuk et al. Arsenic in Private Wells in NH: Report on Focus Groups. Thayer School of Engineering, Dartmouth College, March, 2014.

[16] Therneau, T.M. and E.J. Atkinson, An introduction to recursive partitioning using the RPART routines. 1997, Technical Report 61, Section of Biostatistics, Mayo Clinic, Rochester. URL http://www.mayo.edu/hsr/techrpt/61.pdf.

[17] Flanagan et al. 2014. Influences on domestic well water testing behavior in a Central Maine area with frequent groundwater arsenic occurrence. *Science of the Total Environment*. In press.

[18] Flanagan et al. 2014. Dissemination of well water arsenic results to homeowners in Central Maine: Influences on mitigation behavior and continued risks for exposure. *Science of the Total Environment*. In press.

[19] EPA IRIS, Arsenic, inorganic (CASRN 7440-39-2), Available at: http://www.epa.gov/iris/subst/0278.htm Reported in Inorganic Arsenic: TEACH Chemical Summary, 2007.

[20] National Research Council. *Arsenic in Drinking Water: 2001 Update*. Washington, DC: The National Academies Press, 1999.

[21] National Research Council. *Arsenic in Drinking Water: 2001 Update*. Washington, DC: The National Academies Press, 2001.

[22] Karagas et al. Increase in incidence rates of basal cell and squamous cell skin cancer in New Hampshire, USA. Int J Cancer. 1999 May 17; 81(4):555-9.

[23] Rees et al. Non melanoma skin cancer and subsequent cancer risk. PLoS ONE (2014) vol. 9 (6) pp. e99674

[24] National Cancer Institute, State Cancer Profiles, http://statecancerprofiles.cancer.gov/incidencerates/

[25] Borsuk et al. Arsenic in primate wells in NH: Report on survey response rate and summary statistics. Thayer School of Engineering, Dartmouth College, June 2014.

[26] Personal Communication, Paul Susca, Supervisor, Planning, Protection & Assistance, Drinking Water and Groundwater Bureau, New Hampshire Department of Environmental Services. June 10, 2014.

[27] Personal Communication, Brandon Kernen, NH DES, September 22, 2014

[28] Ayotte et al. Estimated probability of arsenic in groundwater from bedrock aquifers in New Hampshire, 2011: U.S. Geological Survey Scientific Investigations Report 2012–5156, 25 p., 2012, http://pubs.usgs.gov/sir/2012/5156/.

[29] Flanagan, S.M., Belaval, Marcel, and Ayotte, J.D., 2014, Arsenic, iron, lead, manganese, and uranium concentrations in private bedrock wells in southeastern New Hampshire, 2012–2013: U.S. Geological Survey Fact Sheet 2014–3042, 6 p., at http://dx.doi.org/10.3133/fs20143042.

[30] Argos et al. Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study. The Lancet (2010) vol. 376 (9737) pp 252-258

[31] National Cancer Institute, State Cancer Profiles, http://statecancerprofiles.cancer.gov/incidencerates/

[32] Karagas et al. Incidence of transitional cell carcinoma of the bladder and arsenic exposure in New Hampshire. Cancer Causes Control (2004) vol. 15 (5) pp. 465-72

[33] Heck et al. Lung cancer in a U.S. population with low to moderate arsenic exposure. Environ. Health Perspect. (2009) vol. 117 (11) pp. 1718-23

[34] Gilbert-Diamond et al. A population-based case-control study of urinary arsenic species and squamous cell carcinoma in New Hampshire, USA. Environ. Health Perspect. (2013) vol. 121 (10) pp. 1154-60

[35] Ayotte et al. Bladder cancer mortality and private well use in New England: an ecological study. J Epidemiol Community Health (2006) vol. 60 (2) pp. 168-72

[36] Farzan et al. In utero arsenic exposure and infant infection in a United States cohort: a prospective study. Environ Res (2013) vol. 126 pp. 24-30

[37] Wasserman et al. A cross-sectional study of well water arsenic and child IQ in Maine schoolchildren. Environ Health (2014) vol. 13 (1) pp. 23

[38] Farzan et al. In utero and early life arsenic exposure in relation to long-term health and disease. Toxicology and Applied Pharmacology (2013) vol. 272 (2) pp. 384-90

[39] Steinmaus et al. Drinking water arsenic in northern Chile: high cancer risks 40 years after exposure cessation. Cancer Epidemiol Biomarkers Prev (2013) vol. 22 (4) pp. 623-30

[40] Argos et al. Arsenic and lung disease mortality in Bangladeshi adults. Epidemiology (2014) vol. 25 (4) pp. 536-43

[41] Schmidt. Low-dose arsenic: in search of a risk threshold. Environ. Health Perspect. (2014) vol. 122 (5) pp. A130-4

[42] Schmidt. Low-dose arsenic: in search of a risk threshold. Environ. Health Perspect. (2014) vol. 122 (5) pp. A130-4

[43] Kennedy, A.L. Using community-based social marketing techniques to enhance environmental regulation. Sustainability. (2010) vol. 2 pp. 1138-1160

[44] Carlson, A. Surface water protection and water conservation outreach projects using community-based social marketing techniques. NH Department of Environmental Services, Summaries for Reference WD-11-16. (2011)

[45] Rhode Island HEALTH and the University of Rhode Island Cooperative Extension Water Quality Program.

[46] Paul, M.P. et al. In press. A community-driven intervention in Tuftonboro, New Hampshire succeeds in altering water testing behavior

[47] Community Health Partnerships are being used successfully in ME for lead awareness and prevention and are currently being piloted for arsenic in well water. (pers. Comm. Andy Smith and Karyn Butts, ME CDC 8/29/14)

[48] Walker, M., W.D. Shaw, and M. Benson, Arsenic Consumption and Health Risk Perceptions in a Rural Wetern U.S. Area. Journal of the American Water Resources Association, 2006. 42(5): p. 1363-1370.

[49] Madajewicz, M., et al., Can information alone change behavior? Response to arsenic contamination of groundwater in Bangladesh. Journal of Development Economics, 2007. 84(2): p. 731-754.

[50] Liukkonen, B., D. Severtson, and R. Kline-Robach, *Social dimensions of private well testing: why don't people test their well water.* New England Private Well Symposium, 2007.

[51] Stanley, Linda R. Community Readiness for Community Change.Tri-Ethnic Center Community Readiness Handbook. 2nd edition.Tri-Ethnic Center for Prevention Research, Colorado State University, 2014.

[52] Oetting et al. Assessing Community Readiness for Prevention. International Journal of the Addictions. 1995, 30(6). pp. 659-683.