Addressing the Risk of Arsenic Exposures and Associated Health Effects from Private Well Water Use in North Carolina: A Policy Recommendation

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ABSTRACT

Michelle F. Ford: Addressing the Risk of Arsenic Exposures and Associated Health Effects from Private Well Water Use in North Carolina: A Policy Recommendation (Under the direction of Anna P. Schenck)

Arsenic is known to cause cancer and other widespread health effects. Primary exposure sources are water and food. An estimated 14 million Americans obtain drinking water from private (domestic) wells; 3.2 million North Carolinians are among them. A significant proportion of tested wells in North Carolina have arsenic concentrations above the EPA’s 10µg/L Maximum Contaminant Level for public drinking water (Sanders et al., 2011). Private wells are not subject to public drinking water standards and well water testing is generally the well owner’s responsibility. Consequently, data regarding arsenic in private well water remains limited.

This paper studies the relevant literature regarding arsenic exposure effects, well water surveillance for arsenic, well owner risk awareness and testing behaviors, the biologic accumulation of arsenic, effects of socioeconomic status on exposure risk, and related drinking water programs and policies. Ten overarching conclusions are identified and may aid in shaping North Carolina well water monitoring policy. By integrating state environmental health monitoring activities with national monitoring programs, North Carolina could better utilize new and existing well water monitoring resources and develop relevant policy targeting at-risk populations for arsenic exposures.

Keywords: arsenic, well water, monitoring, drinking water, private wells, domestic wells, North Carolina
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List of Abbreviations

ASDWA Association of State Drinking Water Administrators
Atlantic PATH Atlantic Partnership for Tomorrow’s Health
CDC Centers for Disease Control and Prevention
CWH Clean Water for Health
DHHS Department of Health and Human Services
EHS FEST Environmental Health Science FEST
EPA Environmental Protection Agency
EPHT Environmental Public Health Tracking
GAMA Groundwater Ambient Monitoring and Assessment
GIS Geographic Information System
GPS Global Positioning System
IPCS International Programme on Chemical Safety
MCL Maximum Contaminant Level
NAWQA National Water Quality Assessment
NC North Carolina
NCDEQ North Carolina Division of Environmental Quality
NC DPH North Carolina Division of Public Health
NIEHS National Institute of Environmental Health Sciences
NIH National Institutes of Health
NJ New Jersey
NJDEP New Jersey Department of Environmental Protection
NRC National Research Council
PWTA Private Well Testing Act
SDWA Safe Drinking Water Act
SDWIS Safe Drinking Water Information System
SES Socioeconomic status
SWRCB State Water Resources Control Board
UNC-CH University of North Carolina at Chapel Hill
US United States
USGS United States Geological Survey
VOC Volatile Organic Compound
WHO World Health Organization
Introduction

While drinking water exposures to arsenic are known to be a substantial risk factor for adverse health events like cancer, a significant proportion of the US and North Carolina populations drink water from private (domestic) wells that are not monitored for this contaminant. This paper investigates the achievements and limitations of regional, national, and state monitoring and research efforts regarding private well drinking water exposures to arsenic. It seeks to assess the current body of literature to determine the extent of active monitoring of private wells for arsenic. In addition, it evaluates the recent literature pertaining to the association of arsenic exposures with effects, factors affecting well owner monitoring behaviors, monitoring of biologic accumulations of arsenic, and program and policies pertaining to drinking water monitoring at the state and national levels.

The literature review identifies ten prominent concepts relevant to this subject. Based on the findings and subsequent synthesis of conclusions, the goal of this review is to develop policy recommendations to facilitate further active surveillance of at-risk populations, strengthen relationships between local, state, regional, and national monitoring entities, and support efforts to expand the body of scientific knowledge regarding arsenic exposures at low and high levels and their associated health effects.

This subject became one of interest during a practicum opportunity during which I participated in an ongoing study at UNC-CH Lineberger Comprehensive Cancer Center. The study evaluates a suspected association between inorganic arsenic exposures from residential private well water consumption and prostate cancer aggressiveness in North
Carolina men. My practicum experience culminated in a poster presentation at the first-ever National Institute of Environmental Health Sciences (NIEHS)-sponsored Environmental Health Science (EHS) FEST in December, 2016 (Ford, 2016). Through my activities with this research group, I became aware of the risks of arsenic exposure and associated adverse health events among North Carolina well owners. These exposures and risks have, to date, been unmonitored or poorly monitored in North Carolina and other states, given there are few states that mandate well testing at any point during a well’s use. The efforts of researchers in environmental science, cancer biology, epidemiology, and public health have more vigorously highlighted this issue; further research and advances in public health policy will be necessary to affect this significant public health problem.

**Background**

Arsenic has been designated a known carcinogen since 1980, when it was listed in the *First Annual Report on Carcinogens* (National Toxicology Program, 2016). It has been associated with cancers of the skin, lungs, kidneys, and bladder. In addition to its cancer-causing effects, it has been associated with serious conditions of nearly every organ system - dermatologic, gastrointestinal, cardiovascular, pulmonary, hematologic, immunologic, endocrine, and reproductive (Weir, 2002). Exposure of the world’s population to arsenic occurs primarily through consumed food and drinking water, although some occupations carry increased risk of exposure through inhalation and skin contact and some forms have even been used therapeutically (National Toxicology Program, 2016).
Inorganic arsenic is rapidly absorbed from the gastrointestinal tract and its various forms are metabolized by the liver (World Health Organization, 2010), primarily through methylation processes. Methylation of arsenic varies by species, but in humans, inorganic arsenic is heavily methylated to facilitate excretion from the body, primarily in urine. Individuals may vary widely in their abilities to undergo methylation processes, and there is some evidence that a preponderance of arsenic species that are less well-methylated are more likely to cause potentially carcinogenic cellular changes (Tapio & Grosche, 2006). Arsenic also accumulates in hair, fingernails, and toenails. Blood and urine arsenic levels are generally used to evaluate ongoing daily exposure, whereas hair and toenail samples are more useful in monitoring average longer-term exposures. While individual inorganic arsenic species can be determined in urine and drinking water samples, it is not possible to do so in hair or nail samples (Tapio & Grosche, 2006). Identification of inorganic arsenic species in drinking water is not consistently performed for monitoring or research purposes, although this activity could be significant to the evaluation of disease risk (Sanders et al., 2011).

Drinking water exposures are due to the inorganic form of arsenic, of which certain species are considered more toxic (World Health Organization, 2004). Inorganic arsenic originates primarily from dissolving bedrock sediments into surface and groundwater supplies and secondarily from industrial wastes and deposition from the atmosphere. Arsenic accumulates in higher concentrations in groundwater associated with certain geologic formations like sulfide mineral deposits and volcanic rock deposits; the pH of the associated groundwater appears to directly affect the concentration of dissolved arsenic (World Health Organization, 2010). Developing countries like Bangladesh and
India have historically reported high levels (> 1mg/L) of urinary arsenic in residents exposed to extremely elevated (>300µg/L) inorganic arsenic concentrations in drinking water (World Health Organization, 2010). Developed countries like the United States have not typically reported similarly elevated levels of arsenic exposure from drinking water, and associated health risks were generally thought to be minimal. However, extensive epidemiological studies of lower-level arsenic exposures in Taiwan prompted this 2001 statement from the International Programme on Chemical Safety (IPCS):

“Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with ingestion of drinking-water at concentrations ≤50 µg arsenic/litre (World Health Organization, 2004).”

A WHO chemical fact sheet discusses forms and sources of arsenic, known and suspected effects of arsenic exposure, limitations of available evidence in discerning the dose-response relationship, and challenges in testing and remediation of drinking water sources (World Health Organization, 2010). It pinpoints areas of need for further determination of arsenic exposure risks, including this statement:

“The concentration of arsenic in drinking-water below which no effects can be observed remains to be determined, and there is an urgent need for identification of the mechanism by which arsenic causes cancer, which appears to be the most sensitive toxicity end-point.”

Other WHO documents guide policy regarding drinking water safety, although they do not always address arsenic. A WHO issues document (n.d.) addresses the effective use of regulatory frameworks to ensure safe drinking water. These guidelines are applicable to any population’s drinking-water regulations and include the correlation of regulation to relevant public health protection, enactment of regulation that further assesses,
prioritizes, and manages public health risks, and the use of multiple controls to ensure drinking-water safety. WHO also recommends the use of good practice knowledge that is contextually appropriate in developing drinking water regulation. The organization proposes that regulators insure compliance through tools like education/training, good practice incentives, and penalties/sanctions; however, reasonable, achievable, and contextually appropriate regulations must be developed at all levels of government. Regulations should provide well-defined stakeholder responsibilities, adaptability of regulations to changes in context and technology, facilitation of further information gathering and application of that information to the regulatory effort, and assurance of regulatory support by the appropriate programs and organizations that enact and enforce regulations. This report notes that small community water supplies are the most vulnerable to contamination, and effective use of these guidelines would optimize successful regulation of these at-risk water sources (World Health Organization, n.d.).

Because arsenic has been characterized as one of the world’s most significant environmental health hazards (Tapio & Grosche, 2006), the protection of the public from drinking water exposures to arsenic has become a priority in US drinking water policy, even in comparison to other drinking water contaminants. The EPA’s Office of Water requested a 1996 evaluation by the National Research Council to determine if its current drinking water standard for arsenic was valid, based on current scientific literature at that time; that report was published in 1999 (Weir, 2002). Subsequently, in 2001, the EPA requested an update on the scientific literature addressing arsenic’s health effects since the publication of the previous report in 1999 (National Research Council, 2001). The NRC, stimulated by its 1999 and 2001 reports to the EPA, has
since formed a committee tasked with further evaluating epidemiologic studies related to inorganic arsenic exposures and health effects (Zheng & Ayotte, 2015).

In response to the 1999 and 2001 NRC reports and the 2001 IPCS statement, the EPA’s Science Advisory Board recommended a reduction of the MCL for drinking water arsenic from 50µg/L to 10µg/L. In 2002, the EPA finally mandated US public drinking water systems ensure arsenic levels did not exceed an MCL of 10µg/L (Naujokas et al., 2013). While this law affects public drinking water systems, there is no federal mandate related to private drinking water systems, which are usually residential private wells. An estimated 14% of Americans (42 million people) use water from these unregulated private wells (Sanders et al., 2011). A 2009 report by the USGS indicated that, of the 1774 US private wells sampled, 6.8% contained arsenic at levels higher than the EPA’s MCL (DeSimone, Hamilton, & Gilliom, 2009).

Wells in the US are generally drilled wells, anywhere from several hundred to a thousand feet deep, often penetrating consolidated sediments and bedrock (DeSimone et al., 2009). When wells are tested voluntarily, a sample is generally obtained by the well owner from an unfiltered tap and submitted directly to the water quality division of a state’s health department or a certified laboratory recommended by that division. Voluntary water quality testing panels usually include bacteria and nitrates, but may not include other contaminants like heavy metals, pesticides, and radioactive substances. Oregon and New Jersey require well testing at the time of home sales, while only a few states like Florida, Utah, and California offer free voluntary testing or conduct studies to target wells in at-risk regions of the state for contaminants. Less than half of US states require testing at the time of new well construction, but usually this testing only
evaluates nitrates and bacteria, nor does it address long-term water quality monitoring (DeSimone et al., 2009).

**North Carolina well water and arsenic**

In North Carolina, approximately 3.2 million residents obtain their drinking water from private wells, making the state third in number of well water users (Barros, Rudo, & Shehee, 2014). In 2008, state law mandated newly constructed private wells be tested for infectious organisms and inorganic chemicals within 30 days of certification; however, continued monitoring of private wells is not required, nor does this law address the safety of drinking water from older private wells (Barros et al., 2014). A recent North Carolina study estimated that, of 63,000 private wells voluntarily monitored between 1998 and 2010, over 1400 wells contained arsenic levels higher than the 10µg/L EPA limit (Sanders et al., 2011). The study also revealed patterns of heavier arsenic contamination in certain counties on the eastern coast and in the south-central portion of the state. Due to the geologic formations found in the latter region, three south-central counties (Union, Stanley, and Montgomery) exhibited a particularly high proportion of wells with arsenic levels above the MCL (average arsenic concentrations between 5.1 and 8.0µg/L). Based on these findings, North Carolina residents in highly-affected regions using private wells as their primary drinking water source could potentially double their risk of lung and bladder cancer (Sanders et al., 2011).

**Materials and Methods**

The goal of this review was to identify literature sources pertinent in guiding the development of well monitoring policy in North Carolina. Effective monitoring of
inorganic arsenic in private well water would be an essential first step in pursuing future risk remediation. The pursuit of policy development regarding well water monitoring requires consideration of a variety of issues. These considerations include the known health effects and biologic indicators of arsenic exposure, the status of well water surveillance for arsenic, factors that influence voluntary monitoring behaviors among well owners, and current policies and programs addressing drinking water quality.

Search terms targeting these considerations were selected to include any articles pertaining to well water testing, surveillance or monitoring activities, arsenic drinking water exposures, or well water monitoring policies or programs in developed regions of the world. A review of online literature utilized the PubMed and ScienceDirect databases through the UNC-CH’s Health Sciences Library. Keywords used in these searches included the terms "'well water,' "arsenic" “test*,” “monitor*,” “surveil*,” “measur*,” and “concentrat*,” and “level*.” Science Direct results were limited to subjects of environmental science. An additional online search employed the Articles+ database at the UNC-CH Libraries’ “Environmental Studies: Articles” webpage. Keywords in this search included the same terms as the previous databases, limited to the disciplines "environmental sciences" AND "public health" and the subject terms “arsenic” AND "drinking water" AND "drinking-water" AND "public health" AND "public, environmental & occupational health" AND groundwater AND "water wells" AND "well water" AND "ground water" AND monitoring. A bibliography search from these articles identified other relevant studies or grey literature not found directly through the search. A search of the World Health Organization’s website (www.WHO.org) for grey literature using the keywords “drinking water AND well water AND arsenic AND monitoring” was
performed, as well as a similar search of the NIEHS website (www.niehs.nih.gov) using the keywords "well water" AND "arsenic monitoring."

Relevant sources included full text articles published after January 1, 1996, as this marks the year that the EPA most recently initiated a re-evaluation of the drinking water standard for arsenic. Additional criteria for inclusion were arsenic monitoring studies in developed countries; associated disease incidence from arsenic exposure; review articles of drinking water monitoring policy in developed countries; well owner monitoring behavior and/or perceptions; systematic reviews and meta-analyses of these subjects. Articles not published in English, requiring a paid subscription, or without full text access were excluded. Other excluded sources were those published before January 1, 1996 or discussing developing countries, arsenic remediation and monitoring techniques, other contaminants of drinking water, exposure sources other than drinking water, and specific physiologic mechanisms related to arsenic exposures.

Sources were reviewed for inclusion based on title and abstract. Once articles were established as relevant, pertinent information was extracted into data tables for ease of comparison. Extracted information included the article’s primary focus, year published, lead author, population studied (if relevant), data source(s), year(s) the study was performed, study location, study design, sample approach, study group, potential biases identified, study limitations, a brief study description, and a summary of main findings.

Results

The initial literature search from the UNC-CH online library databases yielded 315 articles for review (Figure 1). Searches of the WHO and NIEHS domains resulted in 221
sources to be evaluated, resulting in a total of 536 sources to be screened. Duplicate and non-scholarly records (n=98) were removed; 438 records remained for evaluation. After application of the exclusion criteria, sources were eliminated for the following reasons: 157 lacked relevance to developed countries; 131 pertained to contaminants other than arsenic; 23 discussed physiologic mechanisms associated with arsenic exposure; 58 explored arsenic monitoring or remediation techniques; and 58 pertained to arsenic exposure sources other than drinking water. Eleven relevant articles were retained. A bibliographic search using the reference list from the eleven relevant articles yielded ten additional pertinent sources. Fourteen grey literature sources were generated from all searches. As these 35 sources discussed topics pertinent to the development of well water monitoring policy - arsenic in water surveillance, arsenic exposure effects, well owner risk awareness and testing behaviors, biologic accumulation of arsenic, and related drinking water program/policy analyses - they were ideally suited to guide this policy question.
Articles obtained through literature review of private well water monitoring and arsenic exposures

Free full-text, English language records published between January 1, 1996 and date of search, identified through UNC-CH Libraries database searches (n=315)

Free full-text, English language records published between January 1, 1996 and date of search, identified through WHO and NIEHS online searches (n = 221)

Records screened (n=536)

Duplicates and non-scholarly records removed (n=98)

Records excluded due to lack of relevance to developed countries (n = 157)

Records excluded due to discussion of contaminants other than arsenic (n=131)

Records excluded due to discussion of physiologic mechanisms (n=23)

Records excluded due to discussion of arsenic monitoring or remediation techniques (n=58)

Records excluded due to discussion of exposure sources other than drinking water (n=58)

Grey literature sources added using search and inclusion criteria for original records (n=14)

Records evaluated for eligibility (n=438)

Records included after exclusion criteria applied (n = 11)

Records added from bibliographic search of included articles, using search and inclusion criteria for original records (n=10)

Total sources included based on systematic review, bibliographic search and review, and addition of grey literature sources (n=35)
Arsenic in Water Surveillance

Four articles discussed arsenic in water surveillance (Katner, Lackovic, Streva, Paul, & Trachtman, 2015; Kumar, Adak, Gurian, & Lockwood, 2010; Sanders et al., 2011; Zheng & Ayotte, 2015). While one article evaluated broader US water surveillance of arsenic, the remainder were limited to state or regional surveillance.

An evaluation of US groundwater, public water, and private (well) water data (Kumar et al., 2010) revealed private water supplies had much higher arsenic concentrations than public water supplies, with some regional variation. The study estimated 12% of the US population uses private wells and represents 23% of the US population exposed to arsenic concentrations higher than the EPA’s MCL. Based on these findings, the authors estimated a risk of lung and bladder cancer more than 4.5 times higher for private well water users than for public well water users. Unfortunately, groundwater data sources used in this evaluation were collected from 1976-1996 by the USGS and were not temporally correlated to the 2001 public and private well water exposure data collected by the US Census and the EPA’s SDWIS. Additionally, well water arsenic data was only available to the USGS from a limited number of documented US wells; many wells remain undocumented. The authors concluded that increased monitoring of private wells throughout the US, with better integration of state and national data sources and increased sampling of US regions with limited data regarding well water exposure would improve the quality of further risk assessments (Kumar et al., 2010).

In a review of factors contributing to health risks from well water arsenic exposures in the northeastern US and Canada, Zheng and Ayotte (2015) concluded that current groundwater monitoring and risk assessment tools provide regional estimates of
numbers of households exposed to arsenic above the MCL but do not aid in targeting specific at-risk households. Additionally, the responsibility of private well water monitoring rests on the shoulders of well owners, who often resist monitoring due to issues of cost and optimism bias. The authors advocated for the use of public resources to facilitate private well water arsenic exposure monitoring and treatment.

Among the studies of state arsenic surveillance, only one looked comprehensively at private well water arsenic data for an entire state (Sanders et al., 2011). The study utilized GIS techniques to map well water arsenic data from North Carolina Department of Health and Human Services’ (DHHS) monitoring database (obtained between October 19, 1998 and February 25, 2010) and was able to identify over 1400 private wells that exceeded the MCL for arsenic; of these, 70% were located in ten of the 100 NC counties. Arsenic levels in participating wells ranged from 1-806 µg/L. Of the ten heavily impacted counties, three demonstrated consistent arsenic elevations above MCL for more than a decade; these counties are located in one south-central geologic region containing bedrock arsenic deposits called the Carolina terrane or slate belt. However, study limitations are similar to those noted in national studies – available well samples are contingent on well owner testing behaviors, particularly prior to the 2008 NC mandate requiring testing for all newly constructed wells. Information regarding repeat testing of NC wells with elevated arsenic levels was not available. In addition, GIS technology is limited by the use of GPS devices across the region evaluated; lack of uniform GPS use requires more estimation of geocoding sites (Sanders et al., 2011).

An ecologic study in Louisiana evaluated available data sets from seven sources (state and national) regarding private well drinking water sources and arsenic contamination
While the evaluation identified three parishes as “potential hazards” associated with “high domestic water usage” from private wells, no one data source was a stand-alone resource for arsenic exposure surveillance data. The authors based this conclusion on the large number of unregistered and untested wells in the region of interest and the lack of temporal consistency between data sets. Identified needs included the development of metadata resources obtained through more comprehensive well monitoring policies and outreach.

**Arsenic Exposure Effects**

Eight articles discussed the effects of arsenic exposure from an epidemiologic perspective (Baris et al., 2016; Cantor & Lubin, 2007; Lewis, Southwick, Ouellet-Hellstrom, Rench, & Calderon, 1999; Mink, Alexander, Barraj, Kelsh, & Tsuji, 2008; Naujokas et al., 2013; Saint-Jacques, Parker, Brown, & Dummer, 2014; Tapio & Grosche, 2006; Wasserman et al., 2014). Most large studies used to guide US drinking water policy originate from other developed countries like Taiwan; similarly, five of these eight articles evaluated data from developed countries other than the US (namely Taiwan, Chile, Argentina, and Finland). One of these five was a meta-analysis, one was a systematic review of the literature, and the remaining three were review articles. The three articles evaluating exposure effects in smaller US populations included a cross-sectional study, a case-control study, and a retrospective cohort study.

All of the international studies were subject to issues of exposure misclassification, and only the meta-analysis (Mink et al., 2008) looked exclusively at low-level (<100-200µg/L) arsenic exposure and adverse health outcomes (in this case, bladder cancer risk). This study found that only subjects who had ever smoked showed a significantly
increased bladder cancer risk (relative risk estimate of 1.24, compared to subjects who had never smoked with a relative risk estimate of less than 1.00). While the exposure levels for these groups were widely varied among the participants in the entire study, participants with a narrower exposure range (<100µg/L) were also evaluated and no change in the relative risk estimates was noted (Mink et al., 2008). Additionally, smoking has been determined to be a risk factor for bladder cancer (although the causative agents in cigarette smoke were not discussed), prompting the categorization of smoking behaviors among study participants to account for any potential effect modifying influence exerted by the behavior. A systematic review of epidemiologic studies evaluating arsenic exposures and urinary tract cancers (Saint-Jacques et al., 2014) looked at drinking water arsenic exposure levels of 10, 50, and 150 µg/L, determining that exposure to arsenic in drinking water of 10 µg/L may increase risk of bladder cancer by 40-50%. Increased risk for kidney cancer also appeared to exist, although the authors reported that risks at lower exposures for both cancers are less predictable due to the potential for exposure misclassification.

The remaining three review articles primarily assessed epidemiologic studies of arsenic exposure and its associated health effects; all identified the potential for exposure misclassification to result in selection bias, particularly at lower exposure levels. The broadest review (Naujokas et al., 2013) also evaluated ecologic studies, government and public health publications, and other review articles. This study noted that high level (>3000µg/L) arsenic exposures have been found in US private wells, similar to those in developing countries, and the collective scientific knowledge base regarding arsenic exposure effects in all body systems has significantly broadened; these findings
highlight the importance of more thorough drinking water monitoring, including private wells. The two smaller reviews (Cantor & Lubin, 2007; Tapio & Grosche, 2006) identify gaps in the scientific knowledge base, particularly in chronic low-exposure studies and their associated cancer risks. Both reviews underscore the need for consistent reporting of arsenic exposures from drinking water, larger study sizes, and further epidemiological studies to elucidate effects at all exposure levels.

Regional studies of arsenic exposure and associated effects are limited by the available exposure data and its applicability to observed health effects. A cross-sectional study of 272 Maine schoolchildren's residential well water arsenic exposure, IQ, and biologic accumulation of arsenic (Wasserman et al., 2014) showed children exposed to well water arsenic >5 µg/L had decreases in Full IQ and IQ Indices scores of 5-6 points. However, short-term and long-term well water drinking behaviors were not defined. A much larger case-control study in 3 New England states (Maine, New Hampshire, and Vermont) utilized interviews and surveys of 1213 case patients and 1418 control patients to evaluate factors potentially associated with bladder cancer risk (Baris et al., 2016). The study concluded bladder cancer risk in the most highly exposed participant group was twice that of the lowest exposed when evaluating 40-year lagged cumulative exposure. However, arsenic exposures were estimates based on self-reported water exposures. Factors other than drinking water consumption did not appear to contribute to New England residents' increased risk of bladder cancer.

The retrospective cohort study (Lewis et al., 1999) suffered similar limitations in estimating arsenic exposures from drinking water sources. Regional well water arsenic concentrations were roughly correlated to vital records from defined Mormon
communities in Utah; direct temporal correlation of measured well water arsenic levels with cohort exposure periods was not feasible, and data on confounders was unavailable for the study cohort. Results showed arsenic-associated increases in mortality from hypertensive heart disease were not gender-specific. Additionally, cohort females (n = 1966) had increased mortality from all other heart disease categories, while cohort males (n = 2092) had increased mortality from nephritis and nephrosis as well as prostate cancer. Again, identified research needs included more extensive exposure-effect studies in populations with lower exposure levels.

**Well owner risk awareness and testing behaviors**

The behaviors and risk awareness of well owners were the focus of five recent publications (Chappells et al., 2015; Flanagan, Spayd, Procopio, Chillrud, Braman, et al., 2016; Flanagan, Spayd, Procopio, Chillrud, Ross, et al., 2016; Flanagan, Spayd, Procopio, Marvinney, et al., 2016; Flanagan, Marvinney, & Zheng, 2015), of which three comprised a series of studies published by one research group. All employed surveys, although one research group (Flanagan, Spayd, Procopio, Chillrud, Ross, et al., 2016) followed up with a water sampling intervention and another followed up with interviews (Chappells et al., 2015).

Two studies evaluated arsenic risk awareness among well owners. The cross-sectional study (Chappells et al., 2015) employed surveys (n=420) and follow-up interviews (n=32) sampled from a longitudinal Nova Scotia cohort (Atlantic PATH). The other risk awareness study utilized 525 surveys to determine risk awareness (as well as testing behaviors) among well owners in central Maine (Flanagan et al., 2015). Both studies concluded that well owners tended to show optimism bias – they perceived their well
water was safer and at lower risk of arsenic contamination than surrounding wells; in those owners whose wells had been recently tested, their remembrance of test results was non-existent or significantly lower than actual results. Interviews from the Nova Scotia study showed well owners’ perceptions were influenced less by official sources of information and more by personal experience, local knowledge, and social networks. These studies were limited by participants’ recall and reporting bias. In addition, the Maine study suffered from small sample size and nonspecific water testing behaviors (well owners may have been compelled to test for reasons other than arsenic contamination). The Nova Scotia study was limited by selection bias, as cohort participants were largely urban versus rural and may have been more likely to participate due to higher education level and SES.

Four articles evaluated well owner testing behaviors. Three of these were a series of studies conducted by one research group. The first study in the series (Flanagan, Spayd, Procopio, Chillrud, Braman, et al., 2016) evaluated well owner testing behaviors based on mailed surveys (n=670) to homeowners in New Jersey towns impacted by the PWTA, the majority of which purchased their homes before the law was enacted. The second study in the series (Flanagan, Spayd, Procopio, Chillrud, Ross, et al., 2016) employed household surveys mailed to northern New Jersey homeowners (n=670) with high risk of arsenic exposure and high well water use to determine self-predicted well testing behaviors. An intervention (n=255) followed the survey that allowed surveyed owners to perform follow-up water testing; this portion of the study identified what factors play a role in determining well owner testing compliance. The third study in the series (Flanagan, Spayd, Procopio, Marvinney, et al., 2016) correlated 1287 mailed
household surveys to spatial arsenic occurrence and household income data, where available. The survey targeted 617 central Maine and 670 northern New Jersey households with increased risk of arsenic exposures and high private well water usage to determine if a correlation existed between exposure risk, testing behaviors, and SES.

All three studies in the series were limited by recall and reporting bias on the part of the participants, and well arsenic testing data was not available for the first and third studies in the series. In addition, local well testing promotions that preceded the second study were not temporally or geographically associated with specific study participants (e.g., promotions occurred long before the study and were not conducted uniformly throughout the targeted study regions); well testing behaviors were unknown prior to any promotional efforts in the study regions.

These three studies concluded that legislation mandating well testing significantly increases well testing behaviors. Increased testing behaviors resulted in identification of more contaminated wells and allowed greater opportunities for arsenic remediation of well water (Flanagan, Spayd, Procopio, Chillrud, Braman, et al., 2016). Additionally, self-predicted well owner testing behaviors were found not to align with actual voluntary well testing behaviors, even when testing was at no cost. Education level and SES were noted to be significant predictors of well testing behaviors, and testing cost is a significant barrier to testing behaviors. Testing interventions must target populations with decreased SES to ensure disparities are not worsened by broader interventions (Flanagan, Spayd, Procopio, Chillrud, Ross, et al., 2016). Furthermore, lower SES does decrease testing/treatment behaviors (Flanagan, Spayd, Procopio, Marvinney, et al., 2016)
The fourth study of well owner testing behaviors was the risk awareness study of central Maine well owners discussed above (Flanagan et al., 2015). Regarding testing behaviors, authors observed low testing behaviors in at-risk communities, with better income and higher education level positively affecting testing behaviors. While 78% of respondents reported testing their wells, half had not tested for more than 5 years. In addition, 58.7% of well owners believed they had tested for arsenic, but the majority did not recall or significantly underestimated the arsenic levels reported.

**Biologic Accumulation of Arsenic**

Two articles evaluated the biologic accumulation of arsenic from drinking water exposure. The first was a study of Maine schoolchildren, grades 3-5, in 3 school units from regions of high potential arsenic exposure, described in the earlier discussion of exposure effects (Wasserman et al., 2014). The study found a significant correlation between nail arsenic and water arsenic concentrations, but nail arsenic was not significantly associated with differences in IQ scores. However, increased water arsenic concentrations were significantly associated with decreased IQ scores. The authors admitted that the small number of collected nail samples (n=248) and the limited range of nail arsenic values likely limited their ability to determine if an association exists between nail arsenic and IQ scores.

The other article addressing biologic arsenic accumulation utilized well water inorganic arsenic measurements, toenail clippings and urine specimens from families drinking from private wells, and lifestyle and dietary habit questionnaires (Gagnon, Lampron-Goulet, Normandin, & Langlois, 2016). Participating study households (n=153) were those with private wells selected from a small geographic region of Quebec, Canada;
households were separated into three groups based on their water arsenic levels. Low exposure households were defined as those with water arsenic concentrations < 10µg/L and were randomly selected from available households with those arsenic levels in the region. Intermediate exposure households were defined as those with water arsenic concentrations from 10-20µg/L, and high exposure households were those with ≥20µg/L; all available intermediate and high exposure households were included in the study. Study results showed well water measurements of inorganic arsenic, even when approaching the MCL, still correlated to significant biologic measurements (e.g., urine, toenails) of arsenic in study participants, more notably in adults than in children. Limitations of this study included the small geographic region and small sample size. Additionally, significant sampling bias was a limiting factor, as intermediate and high exposure groups did not employ random sampling techniques.

**Drinking Water Program/Policy Analyses**

Three articles pertained to program or policy analysis. One article (Brown, Van Dyke, Kuhn, Mitchell, & Dalton, 2015) was a program analysis, while two others (Fox, Nachman, Anderson, Lam, & Resnick, 2016; Smith et al., 2002) evaluated policy related to drinking water quality. A program analysis of well water quality and quantity data sets by the Colorado Department of Public Health and Environment and a local Colorado health department was performed as part of a pilot study to integrate and make available private well water data pertinent to public health concerns (Brown et al., 2015). Admittedly, some data sets demonstrated significant limitations, including small size and lack of consistent data elements or quality assurance measures. Notably, only public data was available for use, as private laboratory data was unavailable due to
confidentiality concerns. Since private laboratories likely hold the majority of available Colorado private well water data, the data sets may well be unrepresentative of the state’s private well water quality. However, the pilot study and program analysis demonstrated that useful and timely data sets incorporating GIS could be made available on the Colorado Tracking portal to aid public health outreach and policy efforts. Because this program was facilitated and funded based on Colorado's participation in the CDC's Private Well Initiative and its Environmental Public Health Tracking Network, it could serve as a template for well water monitoring programs in other states, particularly those willing to pursue collaborative relationships with national public health entities like CDC.

One policy analysis reported on expert panel recommendations to the CDC’s CWH program regarding the protection of US private well owners from exposures to drinking water contaminants (Fox et al., 2016). The panel focused on a variety of chemical contaminants, and only one in-person meeting to discuss recommendations was possible. The panel recommended building an "infrastructure of stewardship" to support well owners in maintaining a safe water supply by utilizing coordinated data sources and community outreach to inform those well owners. The increased capacity of well testing was one area of targeted interest, including an increased capability for state and local monitoring of private wells.

The other policy analysis was the only one to specify arsenic in drinking water as its focus, but it was not specific to private well water (Smith et al., 2002). The article reviewed US monitoring policy related to arsenic in drinking water and made future policy recommendations. The policy analysis asserted that uncertainties in
epidemiological studies have delayed the necessary enactment of more stringent arsenic-related drinking water standards. The authors recommended margins of safety be weighted more heavily in considering policy change, particularly in the case of a chemical known to be carcinogenic. The article points out that public health decisions regarding arsenic in drinking water are subject to “analysis paralysis,” as researchers and policymakers focus on statistical analyses and data ambiguities in the face of small margins of safety between known hazardous doses.

**Grey Literature Sources**

Organizational sources of well water monitoring data included the USGS report of US well water quality from 1991-2004 (DeSimone et al., 2009). Among the report’s major findings was that, of the 1774 wells sampled for arsenic testing by a NAWQA study in 48 states, 6.8% were above the MCL. A report (National Association of Chronic Disease Directors, n.d.) of states participating in and funded by the CDC’s Environmental Public Health Tracking Network reveals only 25 states and one city take part in this program that has facilitated monitoring of a variety of environmental health issues, including private well water monitoring and remediation. States that have enhanced their private well monitoring programs through this collaboration include California, Maine, Florida, and Louisiana (Centers for Disease Control and Prevention, 2006). North Carolina is not a participant.

Three reports provided guidance on national issues of water quality from professional associations. Two were obtained from a series published by the American Academy of Pediatrics; the first (Rogan & Brady, 2009) is a technical report describing wells and well water characteristics, contaminants of concern, explains the difference in bottled water
categories, and provides national, state, and tribal contact information. One comment of note in the technical report:

“Testing can be expensive, and the American Academy of Pediatrics encourages states and counties to provide free or low-cost testing to families who need their water tested and cannot afford it.”

In the accompanying policy statement (American Academy of Pediatrics, Committee on Environmental Health, & Committee on Infectious Diseases, 2009), the authors recommend pediatricians incorporate well testing recommendations into their parent education efforts. Parents who are well owners should have their wells inspected and tested every spring and should investigate whether wells are used and tested at vacation homes and child care facilities used by their families. This policy statement goes on to charge local governments with the responsibility of communicating well water health issues, risks, and testing recommendations more transparently to their communities. The statement also recommends testing be free, if possible, to at-risk homeowners; it also advocates state-mandated well testing with disclosure of results to homebuyers at the time of real estate sales.

The third report targeting policy recommendation was the transition paper submitted to the incoming White House administration by the Association of State Drinking Water Administrators (Association of State Drinking Water Administrators, 2016). While the ASDWA primarily supports states’ public water drinking systems, it does facilitate states’ efforts to protect source waters, including the groundwater that supplies private wells. Regarding the regulatory efforts to protect drinking water supplies to all Americans, this transition paper did note, “States support the fundamental contaminant evaluation and rule development processes laid out in the SDWA... However, the overall process
needs to be more nimble and transparent -- especially regarding health effects analyses and risk characterizations, which often lag behind occurrence and analytical methods work” (Association of State Drinking Water Administrators, 2016, p.5).

The remaining grey literature sources reflect state reports, action plans, and policy recommendations. Four states are represented – Maine, New Jersey, North Carolina, and California – with California having the most robust archive.

**Maine**

Maine’s report on the MDI Biological Laboratory Arsenic Summit (Stanton, B. & The Arsenic Prevention and Control Consortium Members, 2015) reviewed the national and state arsenic monitoring and policy histories, emphasizing that the EPA’s 2001 stated goal was to achieve arsenic levels of zero µg/L in drinking water. The report also noted some states have discovered very high levels (>1000µg/L) of arsenic in private well water, akin to levels found in developing countries like Bangladesh. Among the summit’s stated goals were the use of science-based evidence to guide policy regarding arsenic levels in food and water and the increased collaboration between government and non-government agencies regarding regulation setting and enforcement of food and drinking water standards for arsenic.

The summit strongly recommended stakeholders from a variety of organizations improve their collaborative efforts to increase private well water testing in order to decrease water-related arsenic exposures. The document also emphasized the importance of developing novel and improved technologies in drinking water testing and remediation. The summit discussed the lack of cohesive information sources and highlighted New Hampshire’s internet-based application, developed with the support of
the CDC’s Environmental Health Tracking Network, as a model for other states to copy in providing well owners about arsenic risks, well testing recommendations, and remediation options (Stanton, B. & The Arsenic Prevention and Control Consortium Members, 2015).

**New Jersey**

An overview of New Jersey’s Private Well Testing Act (Atherholt, Louis, Shevlin, Fell, & Krietzman, 2009) outlines the history of well water-related occurrences that led to the passage of the PWTA in 2002. The document defines the PWTA as a consumer information law requiring not only testing of private wells at the time of sale of a property but also every 5 years by lessors (with required disclosure of results to tenants). The law also affects sales of properties with small public water systems (less than 15 year-round connections or, if not year-round service, less than an average 25 individuals at least 60 days of the year). Either the buyer or seller (or both parties) may pay for testing.

The results of the mandated well tests are entered by the testing laboratory into New Jersey’s Department of Environmental Protection (NJDEP) database, where they are used to monitor the state’s groundwater quality, benefitting both residents using private wells and state drinking water agencies; the data is also made available to other local, state, and national organizations. Broad testing requirements include arsenic in twelve counties in the northern and central part of the state with significant bedrock geology (Atherholt et al., 2009). The report notes there is no obligation on the part of the buyer or seller to treat the well if arsenic exceeds the New Jersey MCL of $5\mu g/L$, unless the well is of new construction. However, the appropriate public health authority could
require remediation and notify neighbors located within 200 feet of the affected well’s property line.

The PWTA required public outreach programs to be conducted with health departments to educate affected homeowners and real estate professionals about the law itself, the public health issues leading to the enactment of the law, regional geographic variances affecting well safety, and resources available for well treatment. Estimated cost in 2008 for testing was $450-650 per well; the total annual costs of water sample analysis paid by buyers and/or sellers was $6.8 million. Costs to public health entities involved in the program was estimated at $1.5 to 3 million per year; the state’s environmental protection department (NJDEP) maintained two full-time positions at a cost of $240,000 to provide oversight to these entities in 2008.

Funding sources for state and local public health agencies to enact PWTA were limited to an initial $1,000,000 set aside from the New Jersey “Safe Drinking Water Fund” (Atherholt et al., 2009). Unfortunately, the program had not received any additional yearly funding from the state legislature to cover yearly costs of the program, and the state did not increase existing grant funding offered to counties for drinking-water improvements. Single-family homeowners whose well testing results exceeded drinking water standards can apply for 10-year, no-interest loans (as a second mortgage) up to $10,000 from the NJ Housing and Mortgage Finance Agency’s “Potable Water Loan Fund” to assist in well remediation; no other financial assistance was available as of the publication date of this report.

The report described significant data limitations (Atherholt et al., 2009) - no oversight exists to ensure data from sales and leases are submitted to NJDEP, some data could
not be entered into the database software used by NJDEP, and one laboratory did not submit data for three years. Additionally, laboratory certification to decrease sampling errors did not provide quality assurance regarding data collection and management, and samplers often recorded GPS coordinate data incorrectly, requiring extensive correction by NJDEP the first year of testing and prompting the department to provide GPS training to certified laboratories. Other limitations include the absence of well depth data collection (significant to allow monitoring of groundwater quality for certain geologic conditions) and a lack of follow-up confirmatory testing (except in 9% of tested wells due to multiple real estate events for the same property). The absence of corresponding well drilling permits or records to correlate with well test results made accurate distinction of multiple wells on a single property impossible.

North Carolina

One relevant source was reviewed regarding North Carolina and well water arsenic exposures (Barros et al., 2014; Enabling Source Water Protection Project, 2010). The document, an invited commentary to the North Carolina Journal of Medicine, reviews the existing legislation regarding drinking water safety and the gaps in legislative protection for North Carolina residents who drink water from private wells. The report discusses the parameters of 2008 North Carolina legislation requiring testing of newly constructed wells and provides a summary of well water arsenic measurements by county. As noted in the North Carolina study that geomapped arsenic levels from private wells (Sanders et al., 2011), Union and Stanly counties were the top two counties each with nearly 20% of wells exceeding the MCL for arsenic.
This commentary notes the limitations of the well testing program in the state of North Carolina, namely the small percentage of wells that are tested, the majority of which are newly constructed. In addition, these wells are likely tested only once, at the time of certification. In order to promote voluntary well testing, the Division of Public Health has developed a website tool to help inform well owners of testing recommendations; in the case of arsenic, it is recommended to test every 2 years (Barros et al., 2014).

**California**

California has the most extensive documentation of state activities affecting private well water quality. In 2003, the State Water Resources Control Board reported to the California governor and legislature regarding the legislative founding of a Comprehensive Groundwater Quality Monitoring Program (California State Water Resources Control Board, 2003). In this document, the importance of groundwater sources is reviewed, as well as previous legislation related to groundwater quality. The report outlines the benefits of this monitoring program.

The document also describes the GAMA program, under which exists the Voluntary Domestic Well Assessment Project to address private drinking water well safety. The report discusses the current activities of the GAMA monitoring program, which initially samples randomized as well as spatially targeted public supply wells and then incorporates data from designated monitoring points for major aquifers as well as private wells. The report proposes all data should be entered into the Geotracker database used by the SWRCB to provide a statewide digital database of monitoring data. The recommended guideline for well sampling is one well per 25 square kilometers, but no less than 20 wells and no greater than 60 wells per priority region.
The report also discussed criteria for prioritizing the regions to be monitored. Priority regions would be those with large numbers of public supply wells, whereas lower priority regions would be those in mountainous areas or with low use of groundwater. Priority regions would be monitored every 10 years. Regarding what contaminants would be included, the report recommended a three-tiered approach. Low intensity monitoring was recommended for all selected wells using the existing results from the California DHS database. Moderate intensity monitoring was recommended for about 75% of those wells, to include a wider variety of contaminants specified by GAMA, such as low-level VOCs and pesticides. High intensity monitoring of the remaining 25% of selected wells was recommended to encompass a larger array of recognized and emerging contaminants based on USGS NAWQA recommendations. Arsenic monitoring is included in all three monitoring tiers. Among the stated benefits of the program is to “provide... groundwater agencies with trends and long term forecasting which is essential for groundwater management plan growth and preparation, especially if remedial actions become necessary” (California State Water Resources Control Board, 2003).

A similar report by the USGS (Belitz, Dubrovsky, Burow, Jurgens, & Johnson, 2003), in conjunction with the SWRCB, provides technical aspects of the proposed monitoring program and the scientific justifications for its framework and methodology. It discusses the importance of private well monitoring and the resultant data:

“This is especially true for domestic wells because they are sources of drinking water. Past investigations have shown that data from domestic wells can be used to make meaningful assessments, and examination of the DHS public-supply wells database has shown the value of a statewide digital database. The current domestic well sampling
being done by the SWRCB GAMA program (see California State Water Resources Control Board, 2003d), combined with existing data on thousands of domestic wells in the USGS and Department of Pesticide Regulation databases, is an excellent start. These data will be particularly important in ground-water basins where the DHS wells are not present in all areas of the basin."

A 2010 GAMA report discusses the Domestic Well Project in Yuba County, California (California State Water Resources Control Board Groundwater Protection Section GAMA Program, 2010). The project involved sampling of over 1000 private wells in four counties, at no charge to the well owners, between 2002 and 2009. The Yuba County sampling of 128 private wells took place in 2002. The estimated number of private wells in California at the time of this report was over 600,000, with usage of those wells by approximately 1.6 million state residents. The results were used to evaluate groundwater quality, in comparison to groundwater monitoring and public well data. Yuba County has a large number of private wells, available electronic data, and active groundwater monitoring activities, making it appropriate for the project in spite of its low groundwater usage rate compared to other counties. Tested contaminants included bacteria, inorganic chemicals (including arsenic), and VOCs. More than 78% of tested wells had available well completion depth data; nearly 50% were a depth of 100-200 feet below ground surface (California State Water Resources Control Board Groundwater Protection Section GAMA Program, 2010).

In this project, seven private wells exhibited arsenic levels above the MCL of 10µg/L, at a range of 11-29µg/L. GIS mapping of the findings allowed determination of focal variations in well water arsenic and targeting of specific locations within the county that
could be at higher risk of arsenic contamination. The report noted that elevated arsenic levels in private wells was most likely to be from natural sources.

The final grey literature source regarding California’s drinking water is the GAMA Domestic Well Project Summary Results Commonly Observed Chemicals table (California State Water Resources Control Board Groundwater Protection Section GAMA Program, n.d.). The table summarizes results of the monitoring program for five counties sampled from 2002 to 2011 (including the Yuba County report discussed above). The total number of private wells sampled during this period was 1146, with 65 wells (6%) showing arsenic levels above the MCL. The GAMA Domestic Well Project website (http://www.waterboards.ca.gov/gama/domestic_well.shtml) makes clear the project is currently on hiatus, pending further funding, and the State Water Board of California incurred all testing costs. Reports for the remaining four participating counties were also available at that domain.

Discussion

Based on the findings of this literature review, ten prominent themes are noted. First, a significant proportion of the US and NC populations use drinking water from residential private wells. Unfortunately, national and state well monitoring data are often limited, given that testing is unregulated in most states and not all wells are documented. Some US private wells (including a proportion of those in regions of NC) contain arsenic at high levels similar to those found in developing countries. Given the known risk of significant adverse health effects from high exposure levels to arsenic in drinking water, a substantial portion of US and NC residents may be vulnerable if public health policy does not address this risk.
Second, low-level arsenic exposure effects have been incompletely studied, in part due to misclassification of arsenic and well water exposures. However, increased risk of certain cancers may be associated with low-level exposures, particularly to certain inorganic arsenic species. Because private well water use and arsenic monitoring is not routinely documented, characterization of arsenic exposures in populations of private well water users is inconsistent and incomplete, contributing to further exposure misclassification of at-risk populations. More thorough monitoring of these populations would facilitate further evaluation of risk from low-level arsenic exposures and would better identify exposed populations previously missed.

Well owners tend to underestimate exposure risks from well water, even when aware of potential well water contaminants or when well testing has been performed previously. Their perceptions of risk are influenced more by social networks and personal and local knowledge than by official information sources. For these reasons, voluntary well testing is not a reliable method of monitoring arsenic exposures among private well users.

Barriers to well testing behaviors include testing cost, low SES, and decreased education level. Lower SES negatively affects psychological factors that influence testing behaviors, leading to increased exposure risk. State mandated well testing does increase well testing behaviors. Because users of private wells are more likely to live in rural areas where public water supplies are unavailable, they may be more susceptible to these barriers and therefore at greater exposure risk. Removing those barriers through well water policy development would likely decrease exposure risk in these populations.
Increased US monitoring of private wells with improved integration of local, state, and national data to create “metadata” resources would facilitate further research and risk assessment activities. Research and risk assessment activities require representative sampling of at-risk populations to be relevant and valuable. The integration of larger data sets to form metadata resources would allow for improved surveillance at all levels of monitoring.

Further epidemiological studies with large sample sizes and more accurate exposure classification are needed to study lower level arsenic exposure risks. Additionally, exposure risk studies may benefit from determining the mechanism of action of arsenic in cancer development. However, development of larger study populations and sample sizes with better determination of arsenic exposures is only feasible if more complete monitoring of well water is pursued.

Only half of US states collaborate with national monitoring programs like the CDC’s Environmental Public Health Tracking Network. States participating in these programs historically benefit from improved outreach and policy capabilities and may receive increased funding. Enhanced local and state monitoring activities would likewise improve national surveillance capabilities. This type of collaborative relationship could enhance states’ monitoring capabilities for many environmental health hazards, including well water arsenic surveillance. Organizational support from national monitoring programs could allow states to provide consistent well water monitoring to at-risk populations.

Professional medical and environmental associations have advocated for a more robust involvement of state governments in mandating private well testing and providing
subsidized testing to at-risk populations. While this position statement does not address the financial and logistical aspects of this type of policy change, the observations of professionals in the field can be invaluable in identifying relevant public health needs. Additionally, the weight of these stakeholders’ opinions could be an essential factor in the process of developing public health policy.

More adaptable policy change capabilities are recommended for exposures with low margins of safety, even when exposure risks are incompletely understood. Drinking water regulations are most effective when they address and manage relevant public health risks, can adapt to changes in context, and facilitate further information gathering and application. As the compilation of information about arsenic exposures from drinking water expands, drinking water policy should ideally be able to adapt quickly to accommodate populations at risk of significant exposure, namely well water users. States actively pursuing arsenic monitoring of private wells tend to improve their collaborative relationships with federal government and non-government organizations and are able to utilize science-guided policy development to improve their monitoring capabilities. These state programs are still limited by the number of data sources available, the constraints of any legislation regulating well testing, and funding shortages. California’s Groundwater Ambient Monitoring and Assessment Program and associated Domestic Well Project are examples of a state’s successful use of collaborative relationships to expand its monitoring capabilities. Regarding the issue of well water exposures to arsenic, enhanced monitoring activities would further facilitate the development of policy, as those populations at greatest risk would be more readily identified.
Recommendations

Based on this review, full integration of North Carolina’s environmental health monitoring activities with those of national programs like the CDC’s Environmental Public Health Tracking Network would lay the framework for enhanced monitoring of well water users in high-risk areas of the state. Participation in the EPHT program would expand the state’s monitoring capabilities by linking data from health effect and environmental monitoring programs, affording access to additional training resources for state and local environmental health professionals, providing access to environmental health expertise, developing a state Tracking Network, and gaining assistance in developing further environmental health interventions.

The North Carolina Division of Public Health Environmental Health Section would also have access to EPHT’s repository of materials designed to facilitate communication with the public, industry, government officials, and legislators about environmental health risks. Finally, participation in this program would provide additional funding to help support improvements in existing environmental health activities as well as development of new activities. Specific to private well water monitoring, these supportive measures could allow North Carolina’s Division of Public Health and the Division of Environmental Quality to develop targeted pilot studies of private well water arsenic testing similar to the ones enacted by California’s Domestic Well Project.

The expansion of environmental health monitoring activities would subsequently enable North Carolina to institute continuous targeted arsenic monitoring by NC DPH and NCDEQ of private wells in at-risk regions of the state. As noted by Sanders et al. (2011), other types of arsenic risk remediation activities, such as “point-of-use removal,
modification of well depth, and/or use of an alternate water source” may be unavailable in rural areas and can be too costly to implement. Additionally, the comprehensive monitoring of every private well in North Carolina would be an activity too cumbersome and costly in financial and human resources to achieve.

The recent focus on coal ash contamination of North Carolina water sources has led to a larger discussion of attempted well water contaminant remediation versus providing public water supplies for those private well users affected by the spill (North Carolina Department of Environmental Quality, n.d.-a). Contaminants of concern from coal ash regulated by state and federal environmental organizations include mercury, cadmium, and arsenic (United States Environmental Protection Agency, 2016). State legislation was passed in 2016 requiring that Duke Energy provide alternate water supplies to any resident living with one-half mile of the boundary of any facility impounded for coal ash contamination. Two options for alternate water supplies were offered: the provision of alternate public water access or a home filtration system for an existing public or private water supply to be maintained at the expense of Duke Energy. In addition, Duke Energy has been required to provide well water testing to residents within 1500 feet of each of its coal-fired power plants; NC DENR and EPA are collaborating to guide Duke Energy’s well monitoring activities (North Carolina Department of Environmental Quality, n.d.-b). While it will likely be many years before the monitoring and remediation efforts for coal ash contamination can be evaluated for efficacy, an argument could be made that prior monitoring of private wells for a variety of contaminants, including arsenic, would have been beneficial in evaluating the effects of the coal ash spill on North Carolina’s drinking waters. The ability of state environmental health organizations to establish a baseline of
contaminant levels found naturally in identified geologic regions of the state would provide a point of comparison for these contaminants during future environmental pollution incidents.

Well water monitoring programs would need to be offered at no cost to private well users, as cost and SES are known barriers to well testing. Pilot studies described above, as well as data provided through the recent study of well water arsenic measurements and GIS mapping techniques (Sanders et al., 2011) could be used to guide initial testing of wells in at-risk regions of the state. Re-evaluation of testing data with GIS enhancement could be periodically performed to provide further guidance on targeted monitoring efforts. California’s GAMA Domestic Well Project guidelines offer a well-considered template for guiding targeted monitoring of private wells in other states and could complement the existing monitoring activities established through GIS mapping. Enhanced environmental health tracking capabilities and utilization of existing data sources to pinpoint geographic regions with increased risk of well water arsenic contamination could optimize monitoring of high-risk populations.

The major barriers to these policy recommendations are those of human and financial resources. Adequate numbers of adequately trained environmental health personnel may be limited. Additionally, with the current change in the federal administration, funding for the addition of new states to the EPHT appears uncertain at best. Likewise, federal funding for states’ ongoing environmental health monitoring activities may be jeopardized by changes in the federal government’s political climate. Because the state agencies involved in these programs are funded by the North Carolina state legislature, they may also be subject to changes in appropriations that limit their activities. However,
as stated by Sanders et al. (2011), “Targeted monitoring is crucial in reducing the financial cost of testing for speciated arsenic in every monitored well and the methods developed here can be applied to this end towards arsenic in other regions as well as to other contaminants of concern to public health.”

Conclusion

Arsenic exposure is recognized globally as one of the most significant environmental risks to public health. In the United States and the state of North Carolina, a substantial proportion of the population drinks water from private wells largely unmonitored for contaminants like arsenic. Based on recent mapping of wells and correlation with well testing results, a significant number of North Carolina private wells demonstrate arsenic contamination above the limit recognized as the Maximum Contaminant Limit by the EPA. Because further epidemiological studies and environmental health interventions are dependent on more thorough and accurate evaluation of arsenic exposures from these drinking water sources, it is essential that states like North Carolina collaborate with national surveillance programs to improve their monitoring activities and to provide further supportive evidence for continued monitoring. More complete data sources and evidence-based public health recommendations can provide the impetus needed to legally mandate and subsidize targeted monitoring of populations at high risk of arsenic exposure from private well water use.
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