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Arsenic Exposure and Cancer Risk Reduction with Local Ordinance Requiring Whole-House Dual-Tank Water Treatment Systems

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Abstract

Arsenic, a known human carcinogen, occurs naturally in groundwater in New Jersey and many other states and countries. A number of municipalities in the Piedmont, Highlands, and Valley and Ridge Physiographic Provinces of New Jersey have a high proportion of wells that exceed the New Jersey maximum contaminant level (MCL) of 5 µg/L. Hopewell Township, located in Mercer County and the Piedmont Province, has a progressive local ordinance which requires the installation of dual-tank, point-of-entry treatment systems on affected wells. This provided a unique study opportunity. Of the 55 homes with dual-tank POE treatment systems recruited into this study, 51 homes (93%) had arsenic levels under the MCL at the kitchen sink, regardless of years in service and/or maintenance schedule adherence.

Based on the study participants' water consumption and arsenic concentrations, we estimate that Hopewell's arsenic water treatment ordinance, requiring POE dual-tank arsenic treatment, reduced the incidence of excess lifetime (70-year) bladder and lung cancers from 121 (1.7 cancer cases/year) to 16 (0.2 cancer cases/year) preventing 105 lifetime cancer cases (1.5 cases/year). Because the high risk of cancer from arsenic can be mitigated with effective arsenic water treatment systems, this ordinance should be considered a model for other municipalities.

Keywords

Arsenic; Arsenic Water Treatment; Arsenic Exposure; Well Water; New Jersey

INTRODUCTION

Arsenic is a naturally occurring element that is found in rocks and minerals and can enter air, water, and soil. Arsenic exists naturally in all parts of New Jersey at varying levels. In

some areas such as the Piedmont, Highlands, and Valley and Ridge Physiographic Provinces, the chemical and physical properties of the underlying geology allow the arsenic to become mobile and enter groundwater. Arsenic mobilization can occur through oxidation of pyrite and desorption from hematite and clays (Serfes, Spayd et al. 2005). Exposure to arsenic occurs primarily through ingestion and inhalation of contaminated soil, food, water, and air (Caceres, Pino et al. 2005, Ahsan, Chen et al. 2006). Chronic exposure to arsenic has been shown to increase bladder, lung, liver, kidney, and skin cancers (Viraraghavan, Subramanian et al. 1999, Hopenhayn 2006, Cantor and Lubin 2007, Baastrup, Sorensen et al. 2008, Celik, Gallicchio et al. 2008, Han, Weissfeld et al. 2009, Melak, Ferreccio et al. 2014).

Arsenic treatment systems can be divided into two main types, point-of-entry (POE) and point-of-use (POU). POE systems treat raw water where it enters the home thus ensuring that all faucets in the home are receiving treated water. POU treatment systems are a smaller scale version and are usually located under the kitchen sink. POU treatment systems typically treat only one tap and the remaining taps in the home have untreated water. The POE system is the most protective health as water for drinking, showering, bathing and brushing teeth is treated (Spayd, Robson et al. 2015).

Arsenic removal technologies include both physical and chemical processes such as adsorption, ion exchange, and membrane filtration. Adsorptive processes are the preferred method of treatment in New Jersey and mainly include iron, titanium, and iron-impregnated resin adsorbents. Adsorptive processes have been shown to be highly effective at reducing arsenic to below the MCL (Petrusevski and Sharma 2007). In well water treatment, there are two common forms of arsenic to remove, Arsenic (III) and Arsenic (V). As (III) is much more difficult to treat than As (V) due to its neutral charge. Anion exchange and reverse osmosis systems are not effective at removing Arsenic (III), while some treatment processes such as granular ferric adsorptive media remove both Arsenic (III) and Arsenic (V) (Spayd 2009, Spayd, Robson et al. 2012, Gilbert-Diamond, Li et al. 2013).

In 2002, The United States Environmental Protection Agency (U.S. EPA) established a drinking water standard of 10 µg/L for arsenic in drinking water and a maximum contaminant level goal (MCLG) of zero, effective in 2006. New Jersey has the most protective arsenic standard in the United States with a MCL of 5 µg/L, since 2006 (NJDEP 2010).

Our study area of Hopewell Township is located in Mercer County, New Jersey within the Piedmont Province. According to the 2010 US Census, Hopewell Township has a population of 17,304 (US-Census-Bureau 2010). As stated in Hopewell Township Ordinance No. 16–17.3, each home is required to have a water system in compliance with the NJ Safe Drinking Water Act and the Private Well Testing Act. If the home's well water is not in compliance with the arsenic drinking water standard, a whole-house POE treatment system is required. Hopewell further requires a dual-tank granular ferric adsorptive media with sampling ports for raw water, between the arsenic treatment tanks, and treated water. The two arsenic tanks must be installed in series, such that the water flows through each tank individually, not at the same time. The first and second tanks are referred to as the worker tank and safety tank, respectively (Spayd 2007). The “between tanks” sampling tap is located between the worker

and safety tanks. The ordinance also requires maintenance testing every 6 months, but there is no mechanism in place to enforce this provision(Hopewell Township 2008).

In New Jersey, the Private Well Testing Act (PWTa) requires private well owners to test well water for arsenic and other contaminants during real estate transactions and when renting a property that is supplied by a private well. The PWTa does not give the State of New Jersey the regulatory authority to require treatment of private well water. However, individual administrative authorities in New Jersey have the ability to enforce local treatment regulations on private wells. A survey of northern and central New Jersey local and county health departments with reported private well arsenic exceedances in their area was conducted to determine what local regulations are in place for MCL exceedances. Three of the surveyed local health departments require some type of water treatment for PWTa exceedances. One common example is: a local health department can enforce an ordinance passed by their local board of health (their administrative authority) by issuing a certificate of occupancy only when the MCLs of the PWTa contaminants are met in the home's water.Hopewell Township's arsenic treatment ordinance (Ordinance 16–17: Testing and Reporting Requirements for Wells and Septic Systems Prior to Transferring Property), which was passed in 2006 is the most protective in the state, requiring a dual-tank POE treatment system if arsenic is found to be above 5 µg/L in private wells (Hopewell Township, 2006).

MATERIALS AND METHODS

A 2014 review of Hopewell Township Health Department records identified 200 homes with arsenic water treatment systems. These Hopewell Township residents were contacted via mail with a postcard invitation to participate in this study. A follow-up phone call or email was sent if the contact information was available.Compensation for participation was free water testing funded by the New Jersey Geological and Water Survey (NJGWS), a division of the NJ Department of Environmental Protection (NJDEP). The water test was valued at \$200. In addition, homeowners were given an explanation of their water test results with recommendations. A visit to each participant's home was scheduled at their convenience. If the home met the eligibility requirements (i.e. they had a POE dual-tank arsenic treatment system) they were included in the study.

At each home, the water was tested under stressed conditions. The homeowners were asked to turn on two cold water taps for at least ten minutes. It was important to stress the system before sampling because the treatmentmedia requires contact time with the arsenic for effective removal. The system must be stressed to simulate real-life conditions where multiple taps may be running at the same time. Stressing the system allows testing with a realistic contact time. If the homeowner was present during sampling, the importance of stressing the system during water testing was explained to them. It is important to note that for all water sampling, the water should continue to run until the samples are taken.Water samples were collected from 1) the untreated raw watertap,2) the tap between the two arsenic treatment tanks and 3) the kitchen sink tap in 120 ml bottles.A fourth sample was collected if there was also a reverse osmosis water treatment system installed. Water samples were preserved with nitric acid upon delivery at a commercial lab (New Jersey Analytical

Laboratories). U.S. EPA method 200.8 was used for arsenic analysis with a detection limit of 0.1 µg/L.

At each home, a survey was given which included questions to determine water consumption habits. The survey was given in-person and read aloud by the interviewer as the homeowner followed along on a paper copy. The survey data were used to determine arsenic exposure via water ingestion by asking homeowners to estimate their drinking water consumption per day for home tap water and beverages made with tap water. A 20 oz. glass was shown to homeowners to minimize recall bias and aid in accurate estimation of water consumption.

The survey also collected data on length of time the homeowner had lived in the home and the anticipated number of future years in the home. The volume of water consumed, arsenic concentrations and length of exposure were used to calculate past and future arsenic exposure prevented by arsenic treatment systems using Equation 1.

To calculate the arsenic exposure prevented by arsenic treatment systems, the raw arsenic concentration was multiplied by the volume of water consumed per year. The arsenic exposure was also calculated for water at the kitchen sink. Subtracting the kitchen sink arsenic from the raw water arsenic gave the exposure prevented yearly by the arsenic treatment system. Equation 1 was used to calculate future exposure prevented by the arsenic treatment system, assuming the system was effective and arsenic at the kitchen sink would be non-detect or 0.05 µg/L.

The lifetime excess bladder and lung cancer risk due to arsenic exposure was estimated using lifetime average daily exposure (LADE) and the Integrated Risk Information System (IRIS) proposed arsenic cancer slope factor (CSF). The current U.S. EPA IRIS cancer slope factor of 1.5 mg/kg-day is based on the risk of skin cancer for a population drinking high levels of arsenic in Taiwan (Harbison, Bourgeois et al. 2016). Some researchers have used cancer slope factors such as 3.5 mg/kg-day based on data from other arsenic caused cancers (Tsuiji, Yost et al. 2007). In 2010, the U.S. EPA IRIS calculated a new cancer slope factor, 25.7 mg/kg-day, based on lung and bladder cancer for women. This increase was recommended to account for the most common arsenic caused cancers in women, who appear to be the more sensitive group (EPA 2010). This slope factor, which is currently in external review, has been used in subsequent peer reviewed research and is used in the risk calculations in this study (Nachman, Baron et al. 2013). Risk was determined by multiplying the cancer slope factor and LADE and is shown in Equation 2.

RESULTS

Participants were recruited through post cards, social media networks, neighbors, and previous studies. Of the 200 post cards that were mailed to Hopewell Township, NJ residents with existing arsenic water treatment systems, 54 homeowners responded (a 27% response rate) and 47 were recruited into the study. Additionally, 72 Hopewell Township residents that heard about the study through neighborhood social media sites were enrolled if they met the study eligibility criteria. A total of 16 additional homes were enrolled through these concerned neighbor contacts. The remaining 56 homeowners who did not meet the selection

criteria were given detailed instructions on how to test their water. Two additional homeowners who met the eligibility criteria were identified from other NJ Geological and Water Survey (NJGWS) arsenic studies in Hopewell Township and participated in this study.

A final total of 65 homes were enrolled in the study. The average tax assessed home value in Hopewell Township, NJ in 2016 was \$466,300 and was higher in these 65 homes at \$586,888. Additionally, the study population was well-educated with 100% of participants having at least a 2-year college degree. A majority (57%) of the study population had a graduate level degree and 40% had a bachelor's degree.

Of the 65 homes recruited into the study, 55 (84.6%) had a dual-tank POE arsenic treatment system. Table 1 shows the average, minimum and maximum arsenic concentration at each sample location in homes with a dual-tank arsenic POE treatment system. The average arsenic concentrations of the raw water, water between the two arsenic treatment tanks, and water at the kitchen sink were 11.3 µg/L, 3.7 µg/L, and 1.1 µg/L respectively. The highest concentrations measured were 41.6 µg/L in raw water, 38.5 µg/L between the arsenic tanks and 12.8 µg/L at the kitchen sink. A total of 80% of homes exceeded the MCL in raw water. After one arsenic treatment tank, 25% of homes exceeded the MCL. The exceedance was reduced to 7% after the second arsenic tank. None of the homes exceeded the MCL if a reverse osmosis back-up system was installed in addition to their dual-tank arsenic treatment system.

Table 2 shows arsenic exposure parameters for all 55 houses. The average volume of home well water consumed per day was 0.9 L and the average volume of beverages made with home tap water was 0.7 L. Consumption of home tap water varied greatly between 0–7.1 L per day. The exposure data is summarized in Table 3.

A key finding from the survey was that 58.3% of homeowners reported that their arsenic system was installed by the previous homeowner. A complete system with all required parts was installed 39.5% of the time for previous homeowners and 47.6% of the time for current homeowners.

As described in the methods section, past exposure prevented was calculated using Equation 1. An example calculation using the data from a single participant is given here. The raw water concentration at this home was 21.6 µg/L and kitchen sink arsenic concentration was non-detect. For these calculations, 0.05 µg/L, half the detection limit, was used if the result was non-detect. The example homeowner drank 36 oz. water and 16 oz. coffee made with tap water daily or 1.5 L total. The homeowner lived in the home for 8 years and had a POE arsenic treatment system installed before moving in. Equation 1 was used to calculate 94.7 mg of the past arsenic exposure prevented by the treatment system. Past arsenic exposure prevention for the entire study population is shown in Tables 2 and 3.

Equation 1 was also used to estimate future arsenic exposure. An example calculation using the data from the same single participant is given here. This participant intended to live in his home for 7.5 more years, and assuming his water consumption does not change, the effective arsenic treatment system will prevent him from being exposed to an additional 88.8

mg of arsenic. Estimated future arsenic exposure prevented for the entire study population is shown in Tables 2 and 3.

Equation 2 was used to estimate LADE and cancer risk. The average cancer risk from drinking raw water is 7 per 1,000 or 1 in 143. Table 4 shows the exposure parameters and Table 5 shows risk calculations for all sampling locations using average water consumption and concentrations.

The arsenic cancer risk from drinking water without a treatment system was estimated to be 1 in 143. The cancer risk is reduced to 1 in 435 with the addition of one arsenic tank and reduces again to 1 in 1,111 with two arsenic tanks. Based on the technology and analytical testing currently available, a risk of 1 in 33,333 is achievable if the water treatment system is installed per the ordinance and non-detectable concentrations are achieved at the kitchen tap. When applying these risks to the Hopewell Township population of 17,304, 121.3 excess lifetime bladder and lung cancer cases would be caused by drinking untreated (raw) water, 39.7 from having only one arsenic tank, 15.8 from two arsenic tanks and less than 1 from having a functioning POE treatment system with non-detectable arsenic levels at the kitchen sink. Hopewell Township's ordinance requiring two arsenic tanks has the potential to prevent 105–121 excess cancer cases in 70 years.

DISCUSSION

Even with the Hopewell ordinance and a post-installation inspection, only 27 of the 65 homes (41.5%) had a complete system without any missing components, and only 55 (84.6%) had the dual-tank POE treatment system. The most commonly missing treatment system components were sediment filters and water meters, which were present in 69.2% of the homes. Some homes were missing a sampling tap between the arsenic tanks. This prevents the homeowner from testing at this location and knowing when the first arsenic treatment tank is no longer efficiently removing arsenic. When the arsenic concentration is 5 µg/L between the tanks, breakthrough is occurring, and system maintenance is required to change the tanks.

It is unclear what specifically caused these systems to have missing components. Based on anecdotal evidence from homeowners, it is likely due to a combination of problems. One potential problem may be that the previous homeowner was tasked with installing a system during their home sale and both treatment system installers and homeowners were unaware of the existence or purpose of current regulations. Often, the buyer of the home did not have input into the type of system installed. To remedy this, real estate lawyers should stress the importance of the buyer choosing an appropriate arsenic treatment system and making sure all required components are installed. Arsenic water treatment system installers should have a treatment system guidance that includes a checklist of required components. As a final check, inspectors should carefully verify that the arsenic treatment system meets the ordinance requirements.

Even though there are problems with many of the systems meeting the strict ordinance requirements, there is still a significant reduction in arsenic concentrations due to the

regulation and presence of the systems. In the 55 homes with dual-tank POE treatment systems, 80% exceeded the MCL in the raw water. It is likely that the remaining 20% of homes exceeded the standard in a previous water test as arsenic test results can commonly vary $\pm 20\%$. The raw water concentrations ranged from 2.6 – 41.6 $\mu\text{g/L}$ with an average concentration of 11.3 $\mu\text{g/L}$. The proportion of homes exceeding the standard after the first arsenic treatment tank dropped significantly to 24.5%. Hopewell's unique ordinance that requires a second tank in series (called the "safety tank") reduced the proportion of homes exceeding the standard at the kitchen sink down to 7.3%. The average concentration at the kitchen sink was 1.1 $\mu\text{g/L}$ and ranged from non-detectable ($<0.1 \mu\text{g/L}$) to 12.8 $\mu\text{g/L}$. Of the 55 homes with dual-tank POE treatment systems, 51 homes (93%), regardless of years in service and/or maintenance schedule adherence, had arsenic levels under the MCL at the kitchen sink. This is a great reduction in arsenic exceedances as another New Jersey study of water treatment showed only 82% of homes with arsenic treatment were below the MCL at the kitchen sink for arsenic (Flanagan, Spayd et al. 2016). Because of the success in reducing exposure in Hopewell Township, adopting a similar ordinance in towns with arsenic contamination would further promote and protect public health.

Based on arsenic concentrations and average water consumption, the arsenic exposure and risk reduction for homes with treatment systems was calculated. The average homeowner consumed 624.9 L/year (1.7 L/day) of water and beverages made with home tap water. This study specifically asked for home tap water consumed by the homeowner. Bottled water and water consumed from the workplace were not included in the exposure assessment. The average individual's exposure to arsenic prevented by dual-tank POE treatment systems was 23,481.6 μg or 23.5 mg at the time of our sampling. Based on the length of time the homeowners intend to live in their current home, and assuming that all homeowners maintain their systems, an estimated 78.7 mg of future arsenic exposure will be prevented on average. It is important to note that these calculations are for only one person in the home. The actual protection from these arsenic systems is even greater as homes had an average of 3.8 residents and ranged between 1 and 6 residents.

The cancer risk for raw, treated (i.e. between the two arsenic tanks) and kitchen sink water consumption are all relatively high when compared to the public health acceptable risk of 1 in 1,000,000 (0.01 in 10,000). To achieve the one in a million risk, the arsenic concentration would need to be reduced to 1.6 parts-per-trillion. Hopewell Township's ordinance requiring two arsenic tanks has the potential to prevent 105–121 excess cancer cases in 70 years. Because the risk of cancer from arsenic is relatively high and reduction is achievable, in the interest of public health, this type of ordinance should be seriously considered by more towns in New Jersey, other states, and countries interested in reducing their cancer rate.

Strengths and Limitations

This study has a number of limitations. A participation bias may exist as the study participants who were recruited through the postcard and through word of mouth may, in some way, be different than those who did not respond to the recruitment postcard and emails. Some of the homeowners interviewed were not the water treatment decision makers in the family. Additionally, the study population had higher home values and a higher level

of education than Hopewell Township overall and that of many other towns in the State of New Jersey. This may limit the generalizability to other populations. This study relied on the recall of participants to determine their intake of home tap water and therefore their potential daily exposure to arsenic. Though an effort was made to reduce the under or over estimation of water consumption by showing the interviewee a 20 oz. glass when answering the ingestion question, some recall bias may still remain.

There are a number of strengths that made this a unique study opportunity. Hopewell Township is the only town in the New Jersey with an ordinance that requires a dual-tank POE arsenic treatment system for homes that exceeded the New Jersey arsenic MCL on a PWTA water test. Because this requirement has been in place for 13 years (since 2003), sufficient time had elapsed to evaluate the status of the treatment systems a few years after installation. Because of this ordinance, a generous sample size of 55, all within the same town was possible.

CONCLUSION

This study aimed to evaluate the effectiveness of the Hopewell Township arsenic treatment system ordinance. Of the 55 homes with dual-tank arsenic treatment systems, only four homes exceeded the MCL at the kitchen sink. In other words, 92.7% of homes with treatment systems, regardless of years of service and/or maintenance schedule adherence had acceptable arsenic levels under the current New Jersey standard. This speaks to the efficacy of the Hopewell Township ordinance in promoting public health and reducing the risk of contaminated drinking water.

This study also estimated the cancer risk reduction provided by dual-tank POE arsenic water treatment systems. Hopewell Township's ordinance is estimated to prevent 105 (close to 1% of the township population) excess bladder and lung cancers due to the arsenic exposure reduction of whole-house, dual-tank arsenic treatment systems within 70 years. Based on the average water consumption and arsenic concentrations at the kitchen sink, the lifetime risk of bladder and lung cancer from exposure to arsenic was estimated to be in 10,000. It is reasonable to set a goal of 0.3 in 10,000 by achieving non-detect levels of arsenic at every home's kitchen sink. This goal can be achieved through appropriately disseminating this information to homeowners and treatment system installers. Because the risk of cancer from arsenic is so high without treatment and risk reduction is achievable, in the interest of public health, this type of ordinance should be seriously considered by more towns in New Jersey and elsewhere. In addition, an effort should be made to increase the number of homeowners who test yearly and maintain their treatment systems.

Equation 1: Past and Future Arsenic Exposure Prevented by Dual-Tank Arsenic Treatment Systems

$$\begin{aligned} & \left[\left(\text{Raw Water As Concentration} \left(\frac{\mu\text{g}}{\text{L}} \right) \times \text{water consumed} \left(\frac{\text{L}}{\text{year}} \right) \right) \right. \\ & \quad \left. - \left(\text{Treated Water As Concentration} \left(\frac{\mu\text{g}}{\text{L}} \right) \times \text{water consumed} \left(\frac{\text{L}}{\text{year}} \right) \right) \right] \\ & \quad \times \text{years in the home} \\ & = \text{Arsenic exposure prevented by treatment system} \end{aligned}$$

$$\begin{aligned} & \left[\left(\text{Raw Water As Concentration} \left(\frac{\mu\text{g}}{\text{L}} \right) \times \text{water consumed} \left(\frac{\text{L}}{\text{year}} \right) \right) \right. \\ & \quad \left. - \left(\text{Treated Water As Concentration} \left(\frac{\mu\text{g}}{\text{L}} \right) \times \text{water consumed} \left(\frac{\text{L}}{\text{year}} \right) \right) \right] \\ & \quad \times \text{Anticipated Future Years In Home} \\ & = \text{Future arsenic exposure prevented by treatment systems} \end{aligned}$$

Equation 2: Lifetime Average Daily Exposure (LADE) and Cancer Risk

$$\begin{aligned} & \text{Arsenic Concentration} \left(\frac{\mu\text{g}}{\text{L}} \right) \times \text{Tap Water Consumed per day} \left(\frac{\text{L}}{\text{day}} \right) \times \left(\frac{1\text{mg}}{1000\mu\text{g}} \right) \\ & \quad \times \text{average body weight} \left(\frac{1}{70\text{kg}} \right) = \text{LADE} \left(\frac{\text{mg}}{\text{kg} \cdot \text{day}} \right) \\ & \text{Risk} = \text{Cancer Slope Factor} \times \text{LADE} \end{aligned}$$

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REFERENCES

- Ahsan H, Chen Y, Parvez F, Zablotska L, Argos M, Hussain I, Momotaj H, Levy D, Cheng Z, Slavkovich V, van Geen A, Howe GR and Graziano JH (2006). "Arsenic exposure from drinking water and risk of premalignant skin lesions in Bangladesh: baseline results from the Health Effects of Arsenic Longitudinal Study." *Am J Epidemiol* 163(12): 1138–1148.
- Baastrop R, Sorensen M, Balstrom T, Frederiksen K, Larsen CL, Tjonneland A, Overvad K and Raaschou-Nielsen O (2008). "Arsenic in drinking-water and risk for cancer in Denmark." *Environ Health Perspect* 116(2): 231–237. [PubMed: 18288323]
- Caceres DD, Pino P, Montesinos N, Atalah E, Amigo H and Loomis D (2005). "Exposure to inorganic arsenic in drinking water and total urinary arsenic concentration in a Chilean population." *Environ Res* 98(2): 151–159. [PubMed: 15820720]
- Cantor KP and Lubin JH (2007). "Arsenic, internal cancers, and issues in inference from studies of low-level exposures in human populations." *Toxicol Appl Pharmacol* 222(3): 252–257. [PubMed: 17382983]
- Celik I, Gallicchio L, Boyd K, Lam TK, Matanoski G, Tao X, Shiels M, Hammond E, Chen L, Robinson KA, Caulfield LE, Herman JG, Guallar E and Alberg AJ (2008). "Arsenic in drinking water and lung cancer: a systematic review." *Environ Res* 108(1): 48–55. [PubMed: 18511031]
- EPA U (2010). IRIS Toxicological Review of Inorganic Arsenic (Cancer) (2010 External Review Draft) Washington, DC, U.S. Environmental Protection Agency.

- Flanagan S, Spayd S, Procopio N, Chillrud S, Ross J, Braman S and Zheng Y (2016). "Arsenic in private well water trilogy II: Who benefits the most from traditional testing promotion?" *Sci Total Environ*
- Gilbert-Diamond D, Li Z, Perry AE, Spencer SK, Gandolfi AJ and Karagas MR (2013). "A population-based case-control study of urinary arsenic species and squamous cell carcinoma in New Hampshire, USA." *Environ Health Perspect* 121(10): 1154–1160. [PubMed: 23872349]
- Han YY, Weissfeld JL, Davis DL and Talbott EO (2009). "Arsenic levels in ground water and cancer incidence in Idaho: an ecologic study." *Int Arch Occup Environ Health* 82(7): 843–849. [PubMed: 18941772]
- Harbison R, Bourgeois M and Johnson G, Eds. (2016). *Hamilton and Hardy's Industrial Toxicology* Hoboken, New Jersey, John Wiley & Sons, Inc.
- Hopenhayn C (2006). "Arsenic in Drinking Water: Impact on Human Health." *Elements* 2: 103–107.
- Melak D, Ferreccio C, Kalman D, Parra R, Acevedo J, Perez L, Cortes S, Smith AH, Yuan Y, Liaw J and Steinmaus C (2014). "Arsenic methylation and lung and bladder cancer in a case-control study in northern Chile." *Toxicol Appl Pharmacol* 274(2): 225–231. [PubMed: 24296302]
- Nachman KE, Baron PA, Raber G, Francesconi KA, Navas-Acien A and Love DC (2013). "Roxarsone, inorganic arsenic, and other arsenic species in chicken: a U.S.-based market basket sample." *Environ Health Perspect* 121(7): 818–824. [PubMed: 23694900]
- NJDEP. (2010). "A homeowner's guide to arsenic in drinking water" Retrieved 3/19/2014, from <http://www.state.nj.us/dep/dsr/arsenic/guide.htm>.
- Petrusevski B and Sharma S (2007). "Arsenic in Drinking Water." IRC International Water and Sanitation Centre
- Serfes M, Spayd S and Herman G (2005). Arsenic Occurrence, Sources, Mobilization, and Transport in Groundwater in the Newark Basin of New Jersey. *Advances in Arsenic Research*, 175–190.
- Spayd S (2007). "Arsenic Water Treatment for Residential Wells in New Jersey" from http://www.nj.gov/dep/pwta/Arsenic_Treatment.pdf.
- Spayd S (2009). Efficacy of Arsenic Exposure Reduction Via Drinking Water Treatment Systems, The University of Medicine and Dentistry - School of Public Health
- Spayd SE, Robson MG and Buckley BT (2015). "Whole-house arsenic water treatment provided more effective arsenic exposure reduction than point-of-use water treatment at New Jersey homes with arsenic in well water." *Sci Total Environ* 505: 1361–1369. [PubMed: 24975493]
- Spayd SE, Robson MG, Xie R and Buckley BT (2012). "Importance of Arsenic Speciation in Populations Exposed to Arsenic in Drinking Water." *Human and Ecological Risk Assessment: An International Journal* 18(6): 1271–1291.
- Township Hopewell (2008). Ordinance No. 16–17 Testing and reporting requirements for wells and septic systems prior to transfer of property
- Tsuji JS, Yost LJ, Barraj LM, Scrafford CG and Mink PJ (2007). "Use of background inorganic arsenic exposures to provide perspective on risk assessment results." *Regulatory Toxicology and Pharmacology* 48: 59–68. [PubMed: 17346867]
- US-Census-Bureau (2010). 2010 US Census: Hopewell Township, Mercer County, New Jersey.
- Viraraghavan T, Subramanian KS and Aruldoss JA (1999). "Arsenic in Drinking Water, Problems and Solutions." *Wat Sci Tech* 40(2): 69–76.

Figure 1:
Arsenic MCL Exceedance Reduction from Arsenic Treatment Systems

Table 1:

Summary of Arsenic Results

	Raw (µg/L)	Between Arsenic Tanks (µg/L)	Kitchen Sink (µg/L)	Reverse Osmosis (µg/L)
Mean	11.3	3.7	1.1	<0.1
StDev	9.0	6.1	2.3	0.00
Min	2.6	<0.1	<0.1	<0.1
Max	41.6	38.5	12.8	<0.1
(n=)	55	53	55	10

Table 2:**Arsenic Concentrations and Exposure Parameters**

Sampling Site ID	Raw Arsenic Concentration (µg/L)	Arsenic Concentration Between Tanks (µg/L)	Kitchen Sink Arsenic Concentration (µg/L)	Yearly Water Consumption (L)	Past Exposure Prevented by Treatment (µg)	Future Exposure Prevented by Treatment (µg)
1	5.5	NT	0.7	399.7	11,510.3	65,944.5
2	14.5	1.3	<0.1	172.8	17,481.5	37,590.0
3	9.7	<0.1	<0.1	345.7	6,671.1	33,528.5
4	7.8	<0.1	<0.1	2,073.9	32,145.9	161,766.6
5	25.6	10.9	1.4	864.1	62,736.4	331,828.9
6	24.0	5.7	<0.1	259.2	68,297.1	62,217.9
7	10.2	<0.1	<0.1	363.7	11,073.6	74,187.7
8	6.4	1.6	1.7	1,490.6	70,060.0	9,540.1
9	4.3	2.0	<0.1	799.3	6,794.3	34,371.1
10	27.6	38.5	12.8	270.0	47,959.6	29,812.7
11	6.5	0.6	<0.1	1,328.6	34,278.2	172,719.5
12	4.9	0.7	0.5	388.9	6,844.0	5,716.3
13	6.6	3.4	0.5	604.9	7,379.7	59,884.7
14	3.3	<0.1	0.9	518.5	2,488.7	85,549.6
15	10.4	10.9	1.2	691.3	12,720.1	143,792.5
16	6.8	1.6	<0.1	432.1	14,582.3	117,522.7
17	4.5	<0.1	<0.1	280.8	3,749.3	25,276.0
19	5.5	4.1	8.5	0.0	0.0	0.0
20	4.8	1.3	<0.1	2,080.0	29,640.0	99,840.0
21	4.9	0.7	<0.1	518.5	5,029.3	76,216.9
22	21.6	1.4	<0.1	561.7	96,835.3	90,993.7
24	7.5	3.3	<0.1	950.6	56,652.9	71,291.4
25	5.9	1.7	1.0	561.7	19,265.9	99,419.0
26	4.4	2.5	<0.1	518.5	9,021.6	22,813.2
27	6.4	1.3	<0.1	648.1	24,692.7	66,365.8
28	9.7	<0.1	<0.1	216.0	6,254.2	20,955.3
29	7.1	2.4	<0.1	756.1	15,991.9	0.0
30	5.3	<0.1	<0.1	734.5	7,712.4	58,394.1
32	8.8	8.1	<0.1	2,592.4	136,101.7	
34	31.5	9.2	5.9	259.2	6,636.6	163,322.0
35	6.6	<0.1	<0.1	0.0	0.0	0.0
36	7.7	NT	5.2	0.0	0.0	0.0
37	16.7	<0.1	<0.1	453.7	30,214.6	113,644.9
38	8.1	5.9	2.9	691.3	17,974.1	167,988.4

Samplin g Site ID	Raw Arsenic Concentratio n (µg/L)	Arsenic Concentratio n Between Tanks (µg/L)	Kitchen Sink Arsenic Concentratio n (µg/L)	Yearly Water Consumption (L)	Past Exposure Prevented by Treatment (µg)	Future Exposure Prevented by Treatment (µg)
39	19.5	<0.1	<0.1	0.0	0.0	0.0
40	10.8	1.0	<0.1	734.5	47,376.3	79,327.8
41	20.7	1.4	<0.1	496.9	10,260.6	77,140.5
42	2.6	1.2	2.2	993.8	397.5	51,675.4
43	29.0	5.7	0.7	1,080.2	91,706.6	626,499.8
44	38.2	<0.1	<0.1	0.0	0.0	0.0
45	6.1	<0.1	<0.1	388.9	18,820.9	71,161.7
46	8.9	<0.1	<0.1	0.0	0.0	0.0
50	9.8	0.5	<0.1	0.0	0.0	0.0
51	3.1	8.0	2.9	669.7	133.9	68,511.0
52	9.6	8.3	0.6	1,512.2	81,661.0	145,175.1
53	5.9	<0.1	<0.1	0.0	0.0	0.0
54	3.5	4.5	<0.1	518.5	12,521.4	36,293.8
56	8.5	<0.1	<0.1	555.4	9,386.1	47,208.2
57	15.7	10.5	4.2	615.7	14,161.1	96,664.6
58	9.5	3.1	1.0	1,458.2	61,974.9	138,532.1
59	10.6	13.6	0.9	864.1	41,910.7	91,598.6
61	7.0	2.4	0.1	950.6	13,212.7	99,807.9
62	41.6	11.7	2.1	0.0	0.0	0.0
64	14.2	1.4	<0.1	129.6	9,170.7	58,899.6
65	4.9	0.5	<0.1	573.8	0.0	56,236.7

NT = No sampling tap between tanks

Table 3:

Summary of Arsenic Exposure Parameters and Calculations

	Mean	StDev	Min	Max	Total	(n=)
Raw Water As Concentration (µg/L)	11.3	9.0	2.6	41.6	620.8	55
Water Consumed per day (L)	0.9	1.1	0.0	4.7	51.8	55
Beverages Made with Water consumed/day (L)	0.7	1.1	0.0	7.1	39.4	55
Water + Beverages Consumed per day (L)	1.7	1.5	0.0	7.1	94.1	55
Water + Beverages Consumed per year (L)	624.9	555.5	0.0	2592.4	34368.6	55
Kitchen Sink As Concentration (µg/L)	1.1	2.3	<0.1	12.8	59.5	55
Years in Home	6.4	6.1	0.0	29.0	354.0	55
Years with Treatment System	4.5	2.9	0.0	12.0	250.0	55
Anticipated Future Years in Home	17.0	10.6	0.0	50.0	919.5	54
Past Arsenic Exposure Prevented (mg)	23.5	29.7	0.0	136.1	1291.5	55
Future Arsenic Exposure Prevented (mg)	78.7	97.9	0.0	626.5	4247.2	54

Only analyzed homeowners who had a dual-tank POET; one participant refused to answer anticipated years in home

Table 4:

Risk Calculation Parameters

Exposure Parameters	
Average Water Consumed per Day (L)	0.94
Average Beverages Made with Water per day (L)	0.72
Average Water + Beverages Per day (L)	1.71
Total Water Consumed per year (L)	624.88
Arsenic Cancer Slope Factor (mg/kg-day)	25.70
Population of Hopewell Township	17,304

Table 5:

Lung and Bladder Cancer Risk from Arsenic in Drinking Water

	Raw	Between Arsenic Tanks	Kitchen Sink	Achievable	Acceptable Risk
Arsenic Concentration (µg/L)	11.16	3.65	1.45	0.050	0.0016
LADE (mg/kg-day)	0.00027	0.000089	0.000035	0.0000012	0.00000039
CSF	25.7	25.7	25.7	25.7	25.7
Risk	1 in 143	1 in 435	1 in 1,111	1 in 33,333	1 in 1,000,000
Lifetime Risk Applied to the Hopewell Township Population	121.3	39.7	15.8	0.54	0.017