Review of the Drinking Water Maximum Contaminant Level (MCL)

and

Ambient Groundwater Quality Standard (AGQS) for Arsenic

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Review of the Drinking Water Maximum Contaminant Level (MCL) and Ambient Groundwater Quality Standard (AGQS) for Arsenic

Prepared by
Drinking Water and Groundwater Bureau, Water Division
Health Risk Assessment Unit, Air Division
Waste Division

Robert Scott, *Commissioner*
Clark Freise, *Assistant Commissioner*

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New Hampshire Department of Environmental Services
PO Box 95, Concord, New Hampshire 03302-0095
(603) 271-3503

www.des.nh.gov

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1. SUMMARY

1.1 Background

Chapter 190, New Hampshire Laws of 2018 (House Bill 1592), effective June 8, 2018, directs the New Hampshire Department of Environmental Services (NHDES) to "review the ambient groundwater standard for arsenic to determine whether it should be lowered, taking into consideration the extent to which the contaminant is found in New Hampshire, the ability to detect the contaminant in public water systems, the ability to remove the contaminant from drinking water, the impact on public health, and the costs and benefits to affected entities that will result from establishing the standard." Any new ambient groundwater quality standard (AGQS) for arsenic would, in effect, also establish a new drinking water standard (maximum contaminant level – MCL) for arsenic, since public water systems must comply with AGQSs for contaminants that they are monitoring, under New Hampshire Administrative Rule Env-Dw 707.02(b). The AGQS of 10 parts per billion (ppb)[1] applies to facilities that discharge to groundwater. The MCL of 10 ppb applies to public water systems (PWSs) that serve residential populations (community PWSs) and to non-community PWSs that serve the same 25 or more people each day for at least six months of the year, such as schools and places of work with their own wells. Compliance with both the AGQS and MCL are determined on the basis of a running annual average where monitoring is done quarterly, or with annual monitoring at sites with results less than half the standard.

Arsenic is naturally occurring and quite common in New Hampshire's groundwater, and health studies of New Hampshire residents have demonstrated the connection between arsenic and the increased prevalence of conditions including bladder and other cancers and developmental effects on children.[2] More than one-third of community PWSs in New Hampshire have a measurable amount of arsenic in their water. The U.S. Environmental Protection Agency (EPA) typically sets MCLs for drinking water contaminants at a level at which a lifetime of exposure would result in one excess cancer in one million people exposed. However, EPA makes exceptions for contaminants for which the technology is not readily available to detect the contaminant at extremely low levels or to remove the contaminant (treat the water) to such low levels, or when the cost of compliance with a lower standard would be very high. For some contaminants, EPA has established drinking water MCLs with cancer risks in the 10-in-a-million to 100-in-a-million range. The 10 ppb MCL for arsenic is associated with a far greater risk – 3,000 in a

[1] Both the AGQS and the MCL are specified in micrograms per liter (ug/L), a unit of concentration that is equivalent to parts per billion (ppb) in water. In this document, concentrations are stated in ppb except in quoted references that use ug/L.

[2] Dalsu Baris, et.al. Elevated Bladder Cancer in Northern New England: The Role of Drinking Water and Arsenic. Journal of the National Cancer Institute, 108(9). September 2016.; see also Section 5.1.1.2 of this report.

million (roughly 1 in 300) – based on the health effects information available in 2001 when the standard was set.[3] Water systems have been required to meet the new standard since January 23, 2006.

In 2003, EPA began the process of updating the 1988 Toxicological Review upon which the 10 ppb MCL was based. Since then, evidence has continued to mount about the health effects of arsenic at low levels (less than 10 ppb) of exposure. EPA currently expects to complete the review of a revised assessment scope (by the National Academy of Sciences) in 2019, with completion of the risk assessment itself expected in 2021.

The only state that has adopted a standard other than EPA's 10 ppb is New Jersey. In 2003, the State of New Jersey's Drinking Water Quality Institute recommended an arsenic standard of 3 ppb, based on the feasibility of laboratory analytical methods and water treatment technology, but unlike EPA, did not explicitly balance the cost of treatment with the benefit of the reduced health risk. Citing reservations about some of the water treatment methods available to attain the recommended 3 ppb standard, the New Jersey Department of Environmental Protection (NJDEP) adopted a drinking water standard of 5 ppb, which it has been enforcing since 2006.[4] According to NJDEP's most recent report on Public Water Systems, there were no violations of the 5 ppb MCL during 2017 among the state's 582 community and 717 non-transient, non-community water systems.[5]

1.2 Recommendation

After considering a number of factors, as outlined in the Rationale section below, NHDES recommends and proposes that rulemaking be initiated to lower the AGQS for arsenic to 5.0 micrograms per liter (5.0 ppb) and to lower the MCL for arsenic to 5.0 micrograms per liter (5.0 ppb) as a running annual average.

1.3 Rationale

While the costs of compliance with drinking water and groundwater standards of 5 ppb for arsenic would be substantial, the tangible and intangible benefits to public health warrant the recommended reduction. Information gathered and analyses performed for this review enable NHDES to estimate some of those costs and benefits. At the outset, NHDES focused this review on a range of potential MCL/AGQS standards from 3 to 6 ppb, but by the conclusion of the review, determined that both the costs and benefits of a 5 ppb standard could be addressed with greatest confidence. The rationale for NHDES' recommendations is summarized below:

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[3] National Research Council (2001). Arsenic in Drinking Water 2001 Update. Subcommittee to Update the 1999 Arsenic in Drinking Water Report. Board on Environmental Studies and Toxicology. National Research Council. 2001.

[4] New Jersey Department of Environmental Protection. Policy Directive 2003-06, Subject: Drinking Water Standard for Arsenic. October 29, 2003. https://www.nj.gov/dep/commissioner/policy/pdir2003-06.htm

[5] New Jersey Department of Environmental Protection, Division of Water Supply and Geoscience. Annual Compliance Report on Public Water System Violations, July 2017. (pp 7, 19)

- Exposure to inorganic arsenic in drinking water and food at levels below the current MCL of 10 ppb has been shown to increase the risk of a wide range of adverse health effects, including lung, bladder and skin cancer; cardiovascular disease; adverse birth outcomes; illnesses in infants; and reduced IQ. (Section 5.1 of this report)
- For some of these adverse health effects, it is possible to estimate the magnitude of the reduction in risk associated with reducing the MCL from 10 to 5 ppb. In this category are lung, bladder and skin cancer. These are the health effects that were taken into account when EPA set the current MCL at 10 ppb. (Tables 4-6)
- For some additional health effects, convincing information is now available regarding the increased risk in the 5-10 ppb range, but the available information does not make it possible to confidently estimate the number of cases or deaths that could be avoided by lowering the MCL. In this category are adverse birth outcomes, illnesses during the first year of life, and deaths from cardiovascular disease (CVD).
- CVD is of particular interest due to the number of people affected and the evidence that arsenic in the 5-10 ppb range is likely to substantially increase the risk of death from this cause. (Section 5.1)
- The potential for arsenic above 5 ppb to lower the IQ of school children is of great concern, but the available evidence does not enable estimates of the number of children affected with any degree of confidence. However, the potential life-long impact on children must be considered.
- NHDES considered both the tangible (economic) and intangible costs to those affected by the health risks mentioned above.
- Water treatment technologies that are currently used to treat drinking water are capable of reliably maintaining an average arsenic level of 5 ppb, and in many cases lower than that. For a few water systems (those using greensand treatment) relatively minor adjustments in treatment processes can achieve 5 ppb or less. For the vast majority of water systems (those currently using or likely to use adsorption) achieving lower arsenic levels is a matter of replacing their treatment media more frequently. For a substantial number of water systems, maintaining an average arsenic concentration below 5 ppb would not be feasible. This review includes estimates of the costs associated with these changes. (Tables 1 and 2)
- Lowering the groundwater standard (AGQS) from 10 ppb to 5 ppb would affect an estimated 46 municipal landfills, increasing the cost of groundwater monitoring and treatment. Also affected would be an estimated 40 sites with groundwater discharge permits (sewage and septage lagoons, wastewater discharges), which would need to install and operate additional monitoring wells, and treatment systems for private wells. (Table 3)
- Nearly all laboratories that are currently accredited to test for arsenic in public water systems are already able to reliably measure arsenic at levels low enough to ensure that public water systems and other regulated facilities maintain compliance with an MCL and AGQS of 5 ppb.

2. **ABILITY TO DETECT ARSENIC AT LOW LEVELS IN DRINKING WATER AND GROUNDWATER**

NHDES conducted an informal survey of laboratories accredited to analyze water samples from PWSs for compliance with the federal and New Hampshire Safe Drinking Water Acts. All but one of the 17 laboratories that responded indicated that they can analyze for and accurately report on arsenic in drinking water at levels below 2.5 ppb using the equipment and methods they are currently using. The one laboratory currently unable to do so indicated that it would be able to do so given two years' notice.

3. ESTIMATED COST OF COMPLIANCE WITH LOWER MCL

3.1 Costs to public water systems

As noted above, the cost of treatment was a major factor in EPA's 2001 decision to set the MCL for arsenic at 10 ppb rather than a lower level, and the feasibility of treatment was the key factor in New Jersey's 2001 decision to set its standard at 5 ppb rather than 3 ppb. In NHDES' experience working with the public water systems that currently treat for arsenic, maintaining a running annual average of 5 ppb is technically feasible with currently available technology (with significant cost and increased monitoring and operations), but maintaining levels of 3 ppb or below is not technically feasible for a large percentage of systems. In addition to the logistical challenge of very frequent replacement of adsorption media that would be necessitated by an MCL below 5 ppb, there is also the challenge of variability over time. For any PWS treating for arsenic, several factors compound one another to result in a wide range in monitoring results over time: variability in raw water (well water) quality, treatment system performance and laboratory accuracy. Consequently, of the New Hampshire PWSs that currently treat for arsenic, 65% have monitoring results that vary more than 5 ppb within each water system over time. This variability presents a challenge to those PWSs in complying with the current MCL of 10 ppb. In NHDES' judgement, this variability would make compliance with an MCL of less than 5 ppb infeasible for many PWSs.

NHDES' Drinking Water and Groundwater Bureau (DWGB) identified 342 PWSs (community and non-transient, non-community) that would be affected by lowering the MCL into the range of 3-6 ppb. The systems were identified based on the most recent year of arsenic monitoring results from each system. DWGB developed capital and maintenance cost estimates for arsenic treatment for each affected system. Most small water systems (<1,000 population) currently use expendable arsenic adsorptive media and these will be the most affected due to the increased maintenance costs of replacing the media more frequently. Capital cost estimates for new arsenic treatment for small systems were also based on the use of adsorptive media. Other treatment technologies depend on site-specific conditions. Iron-arsenic (greensand) filtration is used by larger systems and by those with naturally occurring iron, and anion exchange is used by some PWSs with a common septic system or sanitary sewer available for

discharge of the concentrated arsenic brine. For this review, it was assumed that existing greensand filtration and anion exchange facilities that are currently achieving levels below 3 ppb would not be affected by a change in MCL. For those greensand and anion exchange facilities that are not achieving these levels, DWGB included the costs for the addition of adsorptive media "polishing" vessels.

The capital cost to install adsorptive arsenic treatment was estimated as $1,000 per gallon/minute (gpm) of capacity, based on DWGB's survey of several major treatment vendors and actual treatment quotes. DWGB estimated the appropriate filter plant capacity for each of the 342 affected systems - either for new treatment or a change in existing treatment - based on the system design flow and projected pumping rate, which in turn are dependent on the system type (community, school, workplace) and the population served. For residential systems, daily flow estimates were based on 70 gallons per capita day (gpcd) and for other system types on design flows as specified in NHDES rule Env-Dw 406, Design Standards for Noncommunity public water systems. Filter sizing was based on treating the daily flow over a six-hour period. For all affected systems, the estimated capital costs are summarized in Table 1.

Table 1. Estimated Capital Cost for PWSs to comply with reduced arsenic MCL

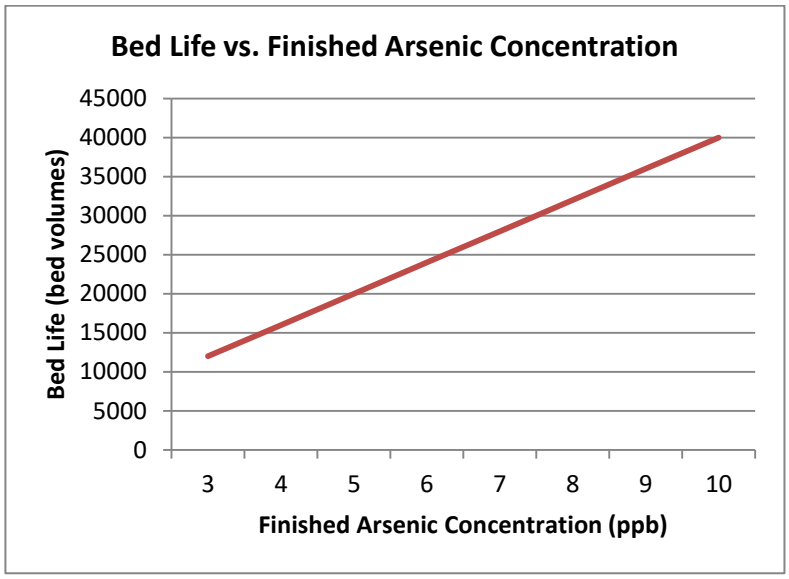
MCL (ppb)	Total Cost for All Systems ($ Million)
6	0.61
5	0.95
4	1.61
3	2.41

The increased maintenance cost of arsenic treatment was estimated based on the cost of replacement of adsorptive media. Systems using iron-arsenic greensand or anion exchange that currently achieve levels below 3 ppb were not considered to be impacted, but those that are not achieving these levels were assumed to require both capital and maintenance costs for the addition of adsorptive media polishing, whether the MCL is set at 3, 4 or 5 ppb. The maintenance cost for arsenic adsorption treatment is largely the cost of periodically replacing the adsorptive media. The longevity of media is expressed in terms of "bed volumes" (BV) of water treated, defined as the volume of water processed divided by the volume of the filter. DWGB obtained information from 21 systems currently treating for arsenic with a wide range of sizes and established a median bed longevity of 40,000 BV, at which point the finished arsenic concentration reaches 10 ppb "breakthough." The cost for media replacement was also reported and resulted in an average cost of $3.6 per 1,000 gallons treated.

Based on arsenic treatment demonstration projects conducted by EPA's Office of Research and Development in New Hampshire from 2004 to 2009, information on adsorption media breakthrough characteristics shows that finished water arsenic concentration is initially very low (< 1 ppb), and steadily increases over time until the media reaches its capacity (e.g., finished water reaches 10 ppb). If the MCL were reduced, the adsorptive media would need to be replaced more frequently. Based on the Demonstration Project data, NHDES estimates the media would need to be replaced twice as often for a

5-6 ppb MCL, and about three times as often for 3-4 ppb MCL. Figure 1 below shows the generalized relationship between bed life and finished arsenic concentration used in developing these cost estimates.

Figure 1



When considering the same 21 systems that were examined in determining the median longevity of the arsenic adsorption media, DWGB found that while pH and silica content affected longevity, as did the influent concentration of arsenic to a lesser extent, the target arsenic concentration of the finished water was the main factor affecting longevity.

Operating and maintenance costs for arsenic treatment were estimated based on the average daily flows for each system. Data from the 21 systems showed an operating cost of $3.6/1,000 gallons. Based on proportionally reduced bed longevity to comply with lower possible MCLs, the estimated total cost for all 342 potentially affected systems was estimated as shown in Table 2.

Table 2. Estimated Current and Increases in PWS Costs to Comply with Reduced Arsenic MCL

MCL (ppb)	Number of Systems Treating	Annual Maintenance Cost ($M)	Capital Cost ($M)	Annualized Capital Cost ($M)	Total Annual Cost ($M)
10*	195	1.49	-	-	-
6	89	3.43	0.61	.06	3.49
5	123	3.88	0.95	.10	3.98
4	188	6.83	1.61	.16	6.99
3	255	7.72	2.41	.24	7.96

*Numbers listed for 10 ppb are systems currently treating and estimated current costs. All others are *increases over current* numbers, except that "systems treating" includes both systems that would add treatment and those that would modify existing treatment as a result of the MCL dropping from 10 to the listed number.

3.2 Costs to private well owners

New Hampshire does not require private wells (wells not serving public water systems) to comply with MCLs. However, if the arsenic MCL were lowered from 10 to 5 ppb, it is expected that some private well users would voluntarily incur costs to ensure their drinking water meets health-based standards. A study conducted by Dartmouth College in 2014 estimated that 93,647 private well users in New Hampshire were drinking water with 5 ppb or greater of arsenic.[6] The average household size in New Hampshire is 2.5 people, so 93,647 people translates to 37,459 households. If all of those households were to install point-of-entry treatment at $3,000 per building, the total cost would be $112 million. If all were to install point-of-use treatment at $1,500 per building, rather than point-of-entry treatment, the cost would be $56 million.

4. ESTIMATED COST OF LOWERING AGQS

Lowering the ambient groundwater quality standard (AGQS) for arsenic would potentially affect the following types of facilities and sites:

- Facilities with groundwater discharge permits issued by DWGB.
- Municipal landfills (permitted by NHDES Waste Division).
- Hazardous waste sites (Waste Division).
- Oil remediation sites (Waste Division).

NHDES considered the costs to owners of these facilities associated with lowering the AGQS from 10 ppb to 5 ppb.

4.1 Facilities with groundwater discharge permits

The approximately 106 facilities with DWGB groundwater discharge permits include wastewater lagoons, sludge lagoons and sites that discharge treated wastewater to the ground or ground surface with the purpose of infiltrating the treated water for disposal through basins, leach fields, or a combination of sheet flow and surface infiltration. Of the permitted facilities, 40 are owned by public entities and at least eight of those facilities struggle to comply with the current 10 ppb standard at least some of the time. Seven of those publicly owned facilities are unlined wastewater lagoons and one is a sludge lagoon. The remainder of the groundwater discharge permit sites are smaller and privately owned, and discharge treated wastewater from a specific facility or manufacturing process.

[6] Mark Borsuk, et.al. Arsenic in Private Wells in NH, Year 1 Final Report. Thayer School of Engineering at Dartmouth and Dartmouth Toxic Metals Superfund Research Program. October 3, 2014 (p 28). http://www.dartmouth.edu/~toxmetal/assets/pdf/Wellreport.pdf

Arsenic is not discharged in significant amounts at any of the sites; rather, arsenic contamination appears to be associated with and influenced by geochemical processes that involve interaction of the wastewater with naturally occurring arsenic-bearing minerals. Currently there are 19 facilities with persistent problems with arsenic at the current standard of 10 ppb; these facilities are in various stages of evaluating and implementing ways to achieve continuous compliance, typically by removing accumulated solids, acquiring more discharge area (land) and in extreme cases by relocating. The costs of the sites with existing issues coming into compliance with a 5 ppb standard are expected to be on the order of $1.1 million, with a recurring annual cost of approximately $240,000 (see Estimated Costs for Groundwater Discharge Permit Sites, attached). With a lowering of the AGQS to 5 ppb, DWGB estimates the number of facilities needing to take on additional costs may double. If that were the case, the compliance costs due to lowering the standard to 5 ppb would be on the order of $2 million, with annual costs on the order of $500,000 (Table 3). In addition, costs to smaller, privately owned facilities that are able to upgrade equipment and wastewater treatment process could range from $50,000 to $500,000 each in increased capital costs.

4.2 Municipal landfills (groundwater management or release detection permits)

The vast majority of solid waste disposal facilities (lined or unlined) or synthetic-lined wastewater treatment lagoons in New Hampshire are municipally owned, and as such, the municipality is responsible for maintaining the water quality systems and monitoring water quality associated with a permit. Approximately 200 of these facilities have groundwater release detection or groundwater management permits (GMPs) issued by the NHDES Waste Division. These permits prescribe programs for periodic groundwater quality monitoring and reporting, provide for groundwater remediation either through active measures or natural attenuation, specify performance standards for remedies, and describe procedures for performing site investigations and implementing corrective action plans.

Arsenic is a contaminant of concern (COC) at a subset of these landfill sites. More frequently, however, arsenic contamination appears to be associated with and influenced by geochemical processes and the presence of naturally occurring arsenic bearing minerals rather than the presence of a well-defined arsenic source. Based on review of the available data, the Waste Division estimates that at least 20% of all landfill sites will require an investigation and/or expansion of the existing GMP based on additional exceedances of an arsenic AGQS of 5 ppb. Furthermore, NHDES has assumed that an arsenic AGQS of 5 ppb would result in a percentage of sites where arsenic will become a new COC. Assuming these percentages of non-compliance for the universe of solid waste sites, the capital costs could be estimated to be in the range of $460,000 to $765,000, and the annual operating costs could range from $190,000 to $315,000 per year (Table 3). These estimates are based on assumptions concerning the cost to install additional monitoring wells, comply with permit sampling and reporting requirements, sample private wells and provide treatment to some percentage of the private wells tested. Attachment 2 includes the assumptions and unit costs. The range of costs in Table 3 represents the initial cost estimate +/- 25%.

Table 3. Estimated Costs for Groundwater Discharge Permit and Landfill Sites if Arsenic AGQS Were Reduced to 5 ppb

(see attachments for detail)

Facility Type	Number of Sites	Total Capital Cost ($ M)	Total Additional Annual Cost ($ M)
Sewage lagoons and other facilities with groundwater discharge permits	40	2.2	0.5
Landfills	46	0.46 - 0.76	0.19 - 0.32

4.3 Hazardous waste and oil remediation sites (groundwater management permits)

Hazardous waste and oil remediation sites include all sites where a hazardous substance or waste, or petroleum product has been released and often have a long-term remediation and management component prescribed and regulated through a NHDES-issued GMP or remedial action plan. There are roughly 515 hazardous waste sites, including State-listed hazardous waste, CERCLA[7] and Brownfield sites, and there are roughly 1,500 petroleum sites, including but not limited to leaking underground or above-ground storage tank sites, and spills that have an open status and are currently regulated by the NHDES Waste Division.

Arsenic contamination in groundwater is not typically a routine COC at these sites. Similar to landfill sites, however, arsenic contamination appears more frequently associated with and influenced by geochemical processes and the presence of naturally occurring arsenic-bearing minerals rather than the presence of a well-defined arsenic source. Often arsenic is a secondary co-contaminant at a waste site but is not the COC driving investigation and cleanup. In addition, arsenic is not routinely required to be analyzed for, as it is at many landfill sites. As a result and based on the limited nature of information associated with arsenic contamination in groundwater at these sites, the capital and annual costs associated with a new AGQS of 5 ppb cannot be determined at this time. A percentage of these sites will incur some additional cost to investigate and/or expand a GMP; however, NHDES anticipates the number of sites to be small.

[7] Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)

5. ESTIMATED BENEFITS OF LOWERING THE MCL

5.1 Estimated numbers of potentially avoided adverse health outcomes

NHDES consulted with EPA-ORD-NCEA-Toxic Pathways Branch, EPA Office of Ground Water and Drinking Water, and Geisel School of Medicine at Dartmouth Epidemiology Department to identify health effects to consider in this review, as well as the most relevant sources of dose-risk data. The many health effects that have been linked to arsenic exposure fall into four groups:

- Health effects for which data exist (published unit risk coefficients) that enable quantitative estimates to be made for exposure below 10 ppb, such that confidence in the estimates is relatively high. These are lung, bladder and skin cancer. (Attachment 3)
- Health effects for which data exist that enable quantitative estimates but have serious limitations, such that confidence in the estimates is low. These are CVD and reduced IQ.
- Health effects for which sufficient data support a connection with low-level (5-10 ppb) exposure but for which data do not seem to exist to enable quantitative estimates to be made for this review. These are adverse birth outcomes, increased infections during the first year of life and gestational diabetes. (Section 5.1.1)
- Health effects for which there is a link with higher levels of exposure but sufficient data were not found to include them in any of the previous groups. These include nonmalignant respiratory conditions, skin lesions, and cancers of the kidney, liver, prostate and pancreas,[8] and are not addressed in this report.

For outcomes with published drinking water unit risk coefficients (cancer cases for lung, bladder and skin, and deaths from lung and bladder cancer) the number of cases or deaths statewide due to exposure in community, work and school PWSs with MCLs of 3, 4, 5, 6, and 10 ppb were estimated. Unit risk coefficients are rates of cancer cases or deaths per unit of exposure. In this analysis, the rates are cancer rates per ppb of arsenic in drinking water, assuming a straight-line, no-threshold relationship, following NRC (2001).

For a description of the approach, see "Background information and steps used to calculate theoretical cancer cases in New Hampshire public water systems from exposure to inorganic arsenic with the current Maximum Contaminant Level (MCL) of 10 micrograms per liter (µg/L) and cancer case reductions assuming the MCL is revised to 6, 5, 4, or 3 µg/L," David Gordon, Environmental Health Program, NHDES, June 14, 2018 (Attachment 3). For comparison with current exposures, the most recent year (average of four quarters for systems monitoring quarterly, most recent sample for other systems) of arsenic monitoring results for PWSs was used.

[8] Communication with EPA, Office of Research and Development, National Center for Environmental Assessment; June 25, 2018.

Results are summarized in "Estimated Cancer Cases for Lung, Bladder, and Skin and Deaths from Lung and Bladder Cancer for NH Public Water System Users Exposed to Arsenic at the Current Maximum Contaminant Level (MCL) and Potential Lower MCLs," David Gordon, Environmental Health Program, NHDES, October 2, 2018 (Attachment 4). Table 4 below summarizes estimates of the numbers of bladder and lung cancer cases statistically attributable to arsenic exposure in community, work, and school PWSs, and the number of cases that could be avoided by lowering the MCL to 3 to 6 ppb. The low end of the ranges is based on the drinking water unit risk reported in Lynch, et al. (2017)[9] and the upper end is based on the unit risk reported in NRC (2001). Table 5 similarly summarizes skin cancer cases. Table 6 summarizes bladder and lung cancer deaths and avoidable deaths associated with the range of MCLs.

Table 4. Estimated Bladder and Lung Cancer Cases over a 70-Year Period Due to Arsenic Exposure from New Hampshire Public Water Systems Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified Maximum Contaminant Levels

MCL (ppb)	Community PWS	Work PWS	School PWS	Total	Bladder and lung cancer cases avoided by lowering MCL
10	30-92	2-6	1-3	33-101	-
6	26-82	1-4	1-3	28-89	5-12
5	25-77	1-3	1-2	27-82	6-19
4	23-70	1-3	1-2	25-75	8-26
3	20-62	1-2	1-2	22-66	11-35

Cancer case estimates are based on NRC (2001) (upper) and Lynch, et al. (2017) (lower).

Table 5. Estimated Skin Cancer Cases over a 70-Year Period Due to Arsenic Exposure from New Hampshire Public Water Systems Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified Maximum Contaminant Levels

MCL (ppb)	Community PWS	Work PWS	School PWS	Total	Skin cancer cases avoided by lowering MCL
10	14	1	1	16	-
6	12	1	1	14	2
5	11	1	0	12	4
4	10	1	0	11	5
3	9	0	0	9	7

The Drinking Water Unit Risk (UR_{dw}) for arsenic from the EPA Integrated Risk Information System (IRIS)[10] was used to calculate cancer cases.

[9] HN Lynch, et.al. Corrigendum to "Quantitative assessment of lung and bladder cancer risk and oral exposure to inorganic arsenic: Meta-regression analyses of epidemiological data" Environmental International 106 :178-206. Environment International, 109. 2017.

[10] USEPA National Center for Environmental Assessment. Integrated Risk Information System (IRIS) Chemical Assessment Summary, Arsenic, inorganic; CASRN 7440-38-2. (Carcenogenicity Assessment last revised

Table 6. Estimated Bladder and Lung Cancer Deaths Due to Arsenic Exposure for Lung and Bladder Cancer over a 70-Year Period from New Hampshire Public Water Systems Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified Maximum Contaminant Levels

MCL (ppb)	Total Cancer Cases from Table 4	Total Deaths		Cancer deaths avoided by lowering MCL	
		Lung	Bladder	Lung	Bladder
10	33-101	19-37	1-9	-	-
6	28-89	16-32	1-8	3-5	0-1
5	27-82	16-30	1-8	3-7	0-1
4	25-75	14-27	1-7	5-10	0-2
3	22-66	13-24	1-6	6-13	0-3

For CVD and lung cancer, NHDES prepared preliminary estimates of the number of avoidable deaths based on "Supporting Information" cited by D'Ippoliti, et al. (2015).[11] This is one of the largest studies conducted in Europe to evaluate the health effects of arsenic in drinking water, in an area with drinking water concentrations in the range of 1 to 80 ppb, in a population with long-term exposure (40 years on average). The study involved 165,609 residents of 17 municipalities, followed from 1990 until 2010. Associations of drinking water arsenic with a number of diseases were found, with the greatest risks found for lung cancer in both sexes; myocardial infarction, peripheral artery disease and chronic obstructive pulmonary disease in males; and diabetes in females. For lung cancer and CVD, the dose-response relationship was broken down into one-ppb increments, revealing effects in the range of 2 to 10 ppb.

The D'Ippoliti study was considered as a potential source of dose-risk information because, while a number of studies have shown a connection between arsenic in drinking water and CVD, this was the only study referenced in conversations with EPA-ORD-NCEA-Toxic Pathways Branch that included dose-risk data in the 1-10 ppb range. In addition to the D'Ippoliti study, Moon, et al. (2017) "conducted a systematic review of general population epidemiological studies of arsenic and incident clinical CVD." [12] The Moon study "supports quantitatively including CVD in inorganic arsenic risk assessment, and strengthens the evidence for an association between arsenic and CVD across low-moderate to high levels." The risks examined in the Moon study are expressed in relation to 10 ppb and therefore were not used in this review. Another team of researchers, based on a review of 20 studies of CVD and low-level arsenic exposure from drinking water, including 12 focusing on exposure in Vietnam, concluded,

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06/01/1995). https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0278_summary.pdf accessed 12/27/2018.

[11] Daniela D'Ippoliti, et. al. Arsenic in Drinking Water and Mortality for Cancer and Chronic Diseases in Central Italy, 1990-2010. PLOS ONE. September 18, 2015.

[12] Katherine A Moon, et. al. A dose-response meta-analysis of chronic arsenic exposure and incident cardiovascular disease. International Journal of Epidemiology, 46(6). December 1, 2017.

"In terms of a guideline for [arsenic] in water, we recommend a guideline of 5 [ppb] in drinking water based on the [50 ppb] [no observed adverse effects level] obtained from this study and uncertainty factor of 10 for extrapolating evidence from epidemiologic studies."[13]

NHDES' preliminary estimates of potentially avoidable CVD and lung cancer deaths, based on the D'Ippoliti study, were included in the attached UNH economic value report (see section 5.2 below) because time constraints made it necessary to move ahead with the UNH work while NHDES' work on health risk estimates was still underway. Ultimately, NHDES decided that, due to a number of limitations in its design, the D'Ippoliti study was not by itself an appropriate source of quantitative risk estimates. Specifically, the quantitative risk results presented by D'Ippoliti, et al. did not account for the key covariates body mass index (BMI) and individual smoking habits, which could affect the magnitude of risk reduction in certain individuals. Quantitative risk estimates that are unadjusted for these covariates could represent overestimations or underestimations for CVD and lung cancer-related mortality in already high-risk groups (e.g., those with high-risk BMIs or smoking habits). However, this does not discount the significant effect of reduced CVD- and lung cancer-related deaths at lower arsenic exposures in the general population.

5.1.1 Other health effects

5.1.1.1 Reduced IQ

In a study of 272 children in grades 3 through 5 from three Maine school districts published in 2014, researchers at Columbia University and the University of New Hampshire found, "Compared to those with [drinking water arsenic (WAs)] < 5 µg/L, exposure to WAs ≥ 5 µg/L was associated with reductions of approximately 5–6 points in both Full Scale IQ ($p < 0.01$) and most Index scores (Perceptual Reasoning, Working Memory, Verbal Comprehension, all p's < 0.05). . . The magnitudes of these associations are similar to those observed with modest increases in blood lead, an established risk factor for diminished IQ."[14] The mean drinking water arsenic concentration in the overall group was 9.9 ppb; roughly half were < 5 ppb. The Maine study is not alone; the researchers noted that this study, "gives confidence to the generalizability of findings from our [2004] work in Bangladesh, where we also observed a steep drop in intelligence scores in the very low range of [drinking water arsenic] concentrations." That study observed a 3.8-point drop in IQ between drinking water at 0 ppb and 10 ppb.[15] A 2011 study of 434 adults also found, "Among older adults, with adjustment for age, gender,

[13] Dung Phung, et.al. Cardiovascular risk from water arsenic exposure in Vietnam: Application of systematic review and meta-regression analysis in chemical health risk assessment. Chemosphere 177. June 2017.
[14] Gail A Wasserman, et. al. A cross-sectional study of well water arsenic and child IQ in Maine schoolchildren. Environmental Health, 13(23). April 1, 2014.
[15] Gail A. Wasserman, et.al. Water Arsenic Exposure and Children's Intellectual Function in Araihazar, Bangladesh. Environmental Health Perspectives, 112 (13). September 2004.

education and ethnicity, WAs (mean WAs = 6.3 µg/L) was associated with a wide range of cognitive skills, including processing speed, executive function, and memory."[16]

5.1.1.2 Adverse birth outcomes, infections in infants and gestational diabetes

The New Hampshire Birth Cohort Study conducted by the Geisel School of Medicine at Dartmouth has relatively recently found connections between low levels of arsenic exposure from water and food, and adverse birth outcomes and infections in infants and gestational diabetes in mothers. Unlike the majority of epidemiological studies on arsenic exposure, the study explores exposures at levels common in New Hampshire.[17] Researchers analyzed 706 mother-infant pairs exposed to arsenic through drinking water (median 0.5 ppb, interquartile range 0.1 – 2.7 ppb) and diet. They measured urinary arsenic from each mother and compared it to the birth weight of her baby, adjusting for maternal pre-pregnancy weight. The researchers found that higher levels of arsenic in the mother's urine during her second trimester were associated with decreased head circumference at birth. They also found associations between arsenic exposure and decreased birth weight and length. In another component of the New Hampshire Birth Cohort Study, in-utero arsenic exposure in a group of 412 mothers whose drinking water arsenic averaged 4.6 ppb (interquartile range 3.1 ppb) was also associated with a higher risk of infection during their babies' first year of life, particularly infections requiring medical treatment, and with diarrhea and respiratory symptoms.[18] Finally, among 1,151 women in the New Hampshire Birth Cohort Study with an average drinking water arsenic concentration of 4.2 ppb (90% were below 10 ppb), each 5 ppb increase in home well water was associated with a 10% increase in the odds of gestational diabetes.[19]

5.2 Estimated value of potentially avoided adverse health outcomes associated with PWSs

In addition to identifying, and where possible estimating the number of, avoided adverse health effects associated with lowering the MCL for arsenic, NHDES considered the economic value of certain avoided adverse health effects. NHDES contracted with the University of New Hampshire (UNH) Department of Natural Resources and the Environment and UNH Department of Economics to do this work.

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[16] Sid E. O'Bryant, et al. Long-term low-level arsenic exposure is associated with poorer neuropsychological functioning: A Project FRONTIER study. International Journal of Environmental Research and Public Health, 8(3). March 2011.

[17] Diane Gilbert-Diamond, et.al. Relation between in utero arsenic exposure and birth outcomes in a cohort of mothers and their newborns from New Hampshire. Environmental Health Perspectives, 124(8). August 2016.

[18] Shohreh F. Farzan , et.al. Infant infections and respiratory symptoms in relation to in utero arsenic exposure in a U.S. cohort. Environmental Health Perspectives, 124(6). June 2016.

[19] Shohreh F. Farzan, et.al. Maternal arsenic exposure and gestational diabetes and glucose intolerance in the New Hampshire birth cohort study. Environmental Health, 15(106). November 2016.

When balancing the costs for PWSs to remove arsenic from water with the benefit of reducing health risks in setting the MCL at 10 ppb in 2001, EPA employed the economic concept of the value of a statistical life (VSL). VSL is not meant to represent the value of an actual human life; rather, it represents the aggregated value that consumers or workers place on avoiding the risk of death due to a particular hazard. Estimates of VSL are often used in evaluating risk-reduction measures such as improvements in highway safety and preventing exposure to environmental toxins. When EPA chose 10 ppb as the MCL for arsenic in 2001, it used a VSL of $6.1 million (1999 dollars). This would translate to $9.3 million in 2018 dollars.[20]

To aid in NHDES' review of the arsenic MCL, the UNH team developed a New Hampshire-specific, drinking water-specific VSL. UNH's approach and analysis are described in "The Economic Benefits of Lowering the Arsenic Maximum Contaminant Level in New Hampshire Municipal Water Supplies" (UNH report, Attachment 5). The VSL value derived by the UNH team was $5.04 million, based on the willingness of respondents to a statewide survey conducted by UNH to pay $35.50 per month ($426 per year) for the reduction in cancer risk associated with reducing the arsenic concentration in their household drinking water from 10 ppb to 3 ppb. At the time the UNH study was initiated, NHDES was considering MCLs as low as 3 ppb, but NHDES later determined that an MCL of 5 ppb would be more appropriate in light of treatment feasibility and the availability of information regarding health effects. The VSL can be applied to consider the reduced risk associated with lowering the MCL to various levels, since VSL represents dollars per unit of risk.

An estimate of the quantifiable willingness to pay for reduced risk of lung and bladder cancers associated with lowering the MCL is presented in Table 7. The estimate applies the VSL of $5.04 million to estimated avoided deaths (Table 6). The value of the many other avoided adverse health impacts is not included. The low end of the range of estimated cancers is based on unit risk coefficients from Lynch, et al. (2017) and the upper end of the range is based on hazard ratios derived from NRC (2001).

Table 7. Annual willingness to pay ($ Million) for reduced risk of lung and bladder cancer associated with lowering the arsenic MCL

	Lung Cancer Deaths		**Bladder Cancer Deaths**		**TOTAL**	
MCL	Low	High	Low	High	Low	High
6	0.216	0.36	0	0.072	0.216	0.432
5	0.216	0.504	0	0.072	0.216	0.576
4	0.36	0.72	0	0.144	0.360	0.864
3	0.432	0.936	0	0.216	0.432	1.15

[20] U.S. Bureau of Labor Statistics Consumer Price Index Inflation Calculator https://www.bls.gov/data/inflation_calculator.htm accessed 11/28/2018

5.3 Estimated value of increased lifetime earnings associated with increased IQ

The UNH report also considered the economic impact of higher IQs associated with lowering the arsenic MCL. Using the Columbia-UNH study of Maine school children as a basis for assuming a 5.5-IQ point difference associated with drinking water with arsenic above 5 ppb, the UNH report estimated a lifetime earnings loss of $148 to $195 million among the estimated 1,248 children currently exposed at > 5 ppb arsenic in New Hampshire community water systems, noting "these estimates of net benefits from reduction of arsenic ingestion on the affected populations should be treated with caution until further epidemiological evidence is available." (Table 7 in the attached UNH report)

5.4 Value of potentially avoided adverse health outcomes associated with private wells

Approximately 46% of New Hampshire households rely on private wells (on-site wells that are not regulated as public water systems) for their water supply. While lowering the MCL would not directly affect private wells and lowering the AGQS would not affect a significant number, NHDES believes that lowering the MCL would prompt many private well users to take action to test and treat water from private wells where the water is above the new MCL, since private well users typically base their perceptions of what is or is not safe on the MCL.

Attachments

1. Estimated Costs for Groundwater Discharge Permit Sites
2. Estimated Costs for Landfill Sites Needing Investigation and/or GMP Expansion
3. Background information and steps used to calculate theoretical cancer cases in New Hampshire public water systems from exposure to inorganic arsenic with the current Maximum Contaminant Level (MCL) of 10 micrograms per liter (µg/L) and cancer case reductions assuming the MCL is revised to 6, 5, 4, or 3 µg/L
4. Estimated Cancer Cases for Lung, Bladder, and Skin and Deaths from Lung and Bladder Cancer for NH Public Water System Users Exposed to Arsenic at the Current Maximum Contaminant Level (MCL) and Potential Lower MCLs
5. The Economic Benefits of Lowering the Arsenic Maximum Contaminant Level in New Hampshire Municipal Water Supplies, December 2, 2018. (UNH Report)

Attachment 1

Estimated Costs for Groundwater Discharge Permit Sites

Isolated Sites : Non-Developed Areas, Able to Expand GDZ, No Private/Public Water Supply Receptors									
	Additional Capital Costs					**Additional Annual Costs**			
	Item	#	Unit Cost	Total		Item	#	Unit Cost	Total
Small GWDP Sites	Mon Well	3	12,000	36,000		Smpl Rnd	6	1,000	6,000
Non POTW sites, usually privately owned	Priv Well Svy	1	1,000	1,000		Rpting	1	2,400	2,400
			Total	*37,000*				*Total*	*8,400*
	2 X	***Add'l sites at 5ppb***		***$ 74,000***		2X	***Add'l sites at 5ppb***		***$ 16,800***
	Additional Capital Costs					**Additional Annual Costs**			
	Item	#	Unit Cost	Total		Item	#	Unit Cost	Total
Large GWDP Sites	Mon Well	6	12,000	72,000		Smpl Rnd	12	1,000	12,000
POTW sites, usually publicly owned	Priv Well Svy	1	1,000	1,000		Rpting	1	2,400	2,400
			Total	*73,000*				*Total*	*14,400*
	12X	***Add'l sites at 5ppb***		***$ 876,000***		12X	***Add'l sites at 5ppb***		***$172,800***
Non-Isolated Sites : Developed Areas, Not (Easily) Able to Expand GDZ, Private/Public Water Supply Receptors Present									
	Additional Capital Costs					**Additional Annual Costs**			
	Item	#	Unit Cost	Total		Item	#	Unit Cost	Total
Small GWDP Sites	Mon Well	2	12,000	24,000		Smpl Rnd	4	1,000	4,000
Non POTW sites, usually privately owned	Priv Well Svy	1	2,500	2,500		Rpting	1	2,400	2,400
	POE-As	3	3,000	9,000		POE O&M	3	1,000	3,000
			Total	*35,500*				*Total*	*9,400*
	Fac Trtmnt	***Range: 10k to 100k***							
	5X	***Add'l sites at 5ppb***		***$ 177,500***		5X	***Add'l sites at 5ppb***		***$ 47,000***

	Additional Capital Costs					Additional Annual Costs			
	Item	#	Unit Cost	Total		Item	#	Unit Cost	Total
Large GWDP Sites	Mon Well	4	12,000	48,000		Smpl Rnd	8	1,000	8,000
POTW sites, usually publicly owned	Priv Well Svy	1	5,000	5,000		Rpting	1	2,400	2,400
	POE-As	6	3,000	18,000		POE O&M	6	1,000	6,000
			Total	*71,000*				*Total*	*16,400*
	Fac Trtmnt	***Flows too large***							
	0X	***Add'l sites at 5ppb***		***$***		0X	***Add'l sites at 5ppb***		***$ -***
	Additional Capital Costs					**Additional Annual Costs**			
Additional 19X sites	**Total Add'l at 5ppb**			**$ 1,127,500**			**Total Add'l at 5ppb**		**$ 236,600**
	8x sites	***Fac Trtmnt Range : $50,000 to $500,000***				*Small Private Facilities Upgrades only			

SUMMARY

For change to 5 ppb As standard:
- Adds ~20 GWDP sites to the list of sites with arsenic compliance issues.
-Adds ~ $1.1M to capital costs
-Adds ~ $240K to annual costs

Existing Compliance
-Potential additional costs to sites with existing compliance issues that exceed the current arsenic standard : ~$480K

Cost impact to small (mostly privately owned) GWDP sites could be greater if WW pre-treatment is put in place: estimate ~ $50K to $500K capital costs

Attachment 2

Estimated Costs for Landfill Sites Needing Investigation and/or GMP Expansion

Est. No. of Sites	**Additional Capital Costs**			**Additional Annual Costs**		
46	A	Monitoring Network Enhancements	$	A	Annual Sampling and Reporting	$
		Monitoring Well Install (assume 3 wells) + Initial Sampling Round	12,000		Annual Sampling/Lab fee (1 round, 3 wells)	3,000
		Receptor Survey	1,000		Annual GMP Reporting	2,400
		Est. Subtotal Capital Cost	13,000		Est. Subtotal Annual Cost	5,400
		Numbers below rounded to the nearest $5,000				
		Est. Total Capital Costs for GMP Expansion	**$590,000**		**Est. Total Annual Monitoring/Reporting Costs**	**$245,000**
7	**B**	Water Supply Well Treatment		B	Water Supply Well Treatment	
		POE Install -assume 3 per site	3,000		Annual O&M of POE (assume 3 per site)	1,000
		Est. Subtotal Cost	**$20,000**		**Est. Subtotal Annual O&M Cost**	**$5,000**
		Est. Capital Cost for GMZ Expansion:	**$610,000**		**Est. Annual Cost for GMZ Expansion:**	**$250,000**
		Low Cost Range (75% of total)	**$460,000**		**Low Cost Range (75% of total)**	**$190,000**
		High Cost Range (125% of total)	**$765,000**		**High Cost Range (125% of total)**	**$315,000**

Attachment 3: Background information and steps used to calculate theoretical cancer cases in New Hampshire public water systems from exposure to inorganic arsenic with the current Maximum Contaminant Level (MCL) of 10 micrograms per liter (µg/L) and cancer case reductions assuming the MCL is revised to 6, 5, 4 or 3 µg/L.

David Gordon, Environmental Health Program, NHDES

June 14, 2018

The Drinking Water and Groundwater Bureau (DWGB) provided the most recent arsenic results (2014-2017 sample dates) for each public water system with arsenic detections and the population served. The results were segregated by system type: community, workplace and schools. Cancer cases were calculated separately for each system type. As yet, PWS with non-detects (NDs) have not been considered although, depending on the laboratory, an ND might be based on a detection limit as high as 5 ppb. NHDES is going to look at water systems with NDs to determine how they can be incorporated into the evaluation.

Water systems were grouped together by arsenic concentration. Arsenic concentrations of the grouped systems were averaged using the low and high concentrations. For example, 35 community water systems with arsenic concentrations between 1.0 and 1.4 µg/L were grouped. Cancer cases for the 35 systems were calculated using the total population served of 42,682 and an arsenic concentration of 1.2 µg/L. Cancer cases for arsenic at the current MCL were calculated with the water system arsenic results grouped together (in 9 groups for community systems) and averaged as in the example above except for systems with arsenic concentrations above 10 µg/L. Systems with arsenic exceeding the MCL were grouped together to sum their populations, but cancer cases for these systems were calculated assuming they would return to compliance with an average arsenic concentration at the MCL. Fractions of cancer cases for each PWS grouping were retained for summing. The summed value was rounded to a whole number.

The same steps were used to calculate cancer cases assuming the other potential MCLs. Systems exceeding the MCL were assumed to reduce arsenic concentrations to the MCL.

The number of expected bladder and lung cancer cases in the exposed populations due to the arsenic in the drinking water was calculated using an arsenic drinking water unit risk (DWUR) of 3.4E-4 per µg/L. This DWUR was derived from the excess lifetime risk of bladder and lung cancer for a combined male and female U.S. population as presented in the National Research Council (NRC) Subcommitte Report (NRC, 2001). EPA is in the process of updating their cancer toxicity values for arsenic. While their toxicity update continues, the cancer risks presented in the NRC Report are considered by EPA as a citable cancer risk estimate. By NRC estimates, bladder cancer cases will exceed lung cancer cases by a ratio of approximately 52 to 48 per 100 cases.

By cancer risk assessment convention, risks are averaged over a 70-year time period, regardless of the actual exposure duration. Exposure durations of 70, 47, and 12 years were used for community, workplace and school water systems, respectively, to calculate cancer estimates. Exposure frequency was seven days/week for community systems and five days/week for workplace and schools. Drinking water ingestion rates were one L/day for workplace and school systems. Community system ingestion rates were one L/day for 59 years and two L/day for 11 years to account for the ages birth to six years and 66 to 70 years, when an individual is expected to be at home.

References:

NRC, 2001. Arsenic in Drinking Water 2001 Update. Subcommittee to Update the 1999 Arsenic in Drinking Water Report. Board on Environmental Studies and Toxicology. National Research Council. 2001.

Attachment 4: Estimated Cancer Cases for Lung, Bladder, and Skin and Deaths from Lung and Bladder Cancer for NH Public Water System Users Exposed to Arsenic at the Current Maximum Contaminant Level (MCL) and Potential Lower MCLs

David Gordon, Environmental Health Program, NHDES
October 2, 2018

Cancer Cases

Tables A41 and A4-2 present alternate estimates of bladder and lung cancer cases combined, based on two different sources of dose-risk information. For all estimates (Tables A4-1-5), arsenic concentrations in PWSs are assumed to be at the MCL value.

Table A4-1: Estimated Bladder and Lung Cancer *Cases* over a 70-Year Averaging Period Due to Arsenic Exposure from New Hampshire Public Water Systems, Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified MCLs

MCL	Community PWS	Work PWS	School PWS	Total
10	92	6	3	101
6	82	4	3	89
5	77	3	2	82
4	70	3	2	75
3	62	2	2	66

µg/L = micrograms per liter. Cancer case estimates are based on NRC, 2001.

Reference

NRC 2001. Arsenic in Drinking Water 2001 Update. Subcommittee to Update the 1999 Arsenic in Drinking Water Report, Board on Environmental Studies and Toxicology, National Research Council.

Table A4-2: Estimated Bladder and Lung Cancer *Cases* over a 70-Year Averaging Period Due to Arsenic Exposure from New Hampshire Public Water Systems, Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified MCLs

MCL	Community PWS	Work PWS	School PWS	Total
10	30	2	1	33
6	26	1	1	28
5	25	1	1	27
4	23	1	1	25
3	20	1	1	22

The cancer Drinking Water Unit Risk (UR_{dw}) used in the calculations is from Lynch, et al. 2017.

References:

Lynch, et al. 2017. Quantitative assessment of lung and bladder cancer risk and oral exposure to inorganic arsenic: Meta-regression analyses of epidemiological data." Environmental International 106: 178-2006.

Lynch, et al. 2017. Corrigendum to "Quantitative assessment of lung and bladder cancer risk and oral exposure to inorganic arsenic: Meta-regression analyses of epidemiological data" Environmental International 106: 178-2006. Environmental International 109: 195-196.

Table A4-3: Estimated Skin Cancer *Cases* over a 70-Year Averaging Period Due to Arsenic Exposure from New Hampshire Public Water Systems, Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified MCLs

MCL	Community PWS	Work PWS	School PWS	Total
10	14	1	1	16
6	12	1	1	14
5	11	1	0	12
4	10	1	0	11
3	9	0	0	9

The Drinking Water Unit Risk (UR_{dw}) for arsenic from the EPA Integrated Risk Information System (IRIS) was used to calculate cancer cases. Cancer cases that are zero indicate that the value calculated was less than 0.50 cases. Deaths from skin cancer were not calculated because non-melanoma skin cancer is rarely fatal. µg/L = micrograms per liter

Reference:

IRIS. 2018. Assessment for inorganic arsenic. Integrated Risk Information System. Environmental Protection Agency, National Center for Environmental Assessment (NCEA), Office of Research and Development (ORD).

Cancer Deaths

In Tables A4-4 and A4-5, estimates of cancer *deaths* are presented, based on Tables A4-1 and A4-2. To estimate deaths, the percentage of lung and bladder cancer cases in New Hampshire that result in death was calculated from the Tables "New Cancer Cases per 100,000 Rank" and "Cancer Deaths per 100,000 Rank" in the publication New Hampshire Cancer Report Card, (April 2009) authored by the New Hampshire Department of Health and Human Services, Office of Health Statistics and Data Management.

The percentages of cancer cases that result in death were then applied to the estimates of cancer cases in the New Hampshire public water system presented in Table A4-1, resulting in Table A4-4. The cancer case estimates in Table A4-1 have been apportioned between lung and bladder cancer based on cancer target organ risk estimates in the NRC document Arsenic in Drinking Water 2001 Update.

The cancer case estimates in Table A4-2 have been apportioned between lung and bladder cancer based on target organ cancer risk estimates in the two 2017 Lynch, et al. journal articles, resulting in Table A4-5.

Table A4-4: Estimated Bladder and Lung Cancer *Deaths* Due to Arsenic Exposure for Lung and Bladder Cancer over a 70-Year Averaging Period from New Hampshire Public Water Systems, Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified MCLs

MCL (µg/L)	Total Cancer Cases from Table 1	Total Deaths	
		Lung	Bladder
10	101	37	9
6	89	32	8
5	82	30	8
4	75	27	7
3	66	24	6

Only the Total column **from Table 1** was converted to lung and bladder cancer deaths because the low numbers in the “Work” and “School” PWS would result in values well below 1.

Table A4-5: Estimated Bladder and Lung Cancer *Deaths* over a 70-Year Averaging Period Due to Arsenic Exposure from New Hampshire Public Water Systems, Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified MCLs

MCL (µg/L)	Total Cancer Cases from Table 1	Total Deaths	
		Lung	Bladder
10	33	19	1
6	28	16	1
5	27	16	1
4	25	14	1
3	22	13	1

Only the Total column **from Table A4-2** was converted to lung and bladder cancer deaths because the low numbers in the “Work” and “School” PWS would result in values well below 1.

The Economic Benefits of Lowering the Arsenic Maximum Contaminant Level in New Hampshire Municipal Water Supplies

December 10, 2018

John Halstead

Department of Natural Resources and the Environment

University of New Hampshire

Scott Lemos

Robert Mohr

Robert Woodward

Department of Economics

University of New Hampshire

Prepared for the New Hampshire Department of Environmental Services

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I. INTRODUCTION

In January 2001, the US Environmental Protection Agency (EPA) lowered the Maximum Contaminant Level (MCL) for arsenic in drinking water from 50 parts per billion, the equivalent of 0.050 mg/L or 50 ppb, to its current level of 10 parts per billion (ppb). As part of the process for arriving at this Arsenic Rule, the EPA also considered the potential costs and benefits of setting the MCL at lower a lower level. In the Federal Register, EPA announced "a health-based, non-enforceable Maximum Contaminant Level Goal (MCLG) for arsenic of zero and an enforceable Maximum Contaminant Level (MCL) for arsenic of 10 ppb. This regulation will apply to non-transient non-community water systems, which are not presently subject to standards on arsenic in drinking water, and to community water systems" (Federal Register 2001a: 6976-7066). As part of the process, EPA also requested comment on data and technical analyses which would support setting the MCL, at 3 ppb (the feasible level), 5 ppb (the level proposed in June 2000), 10 ppb (the level published in the January 2001 rule), or 20 ppb (Federal Register 2001b: 37617-37631).

On June 8, 2018, Governor Sununu approved HB 1592, an act that requires the New Hampshire Department of Environmental Services (NHDES) to "review the ambient groundwater standard for arsenic to determine whether it should be lowered, taking into consideration the extent to which the contaminant is found in New Hampshire, the ability to detect the contaminant in public water systems, the ability to remove the contaminant from drinking water, the impact on public health, and the costs and benefits to affected entities that will result from establishing the standard." While the NHDES staff has the expertise to provide detailed information about capital and operational costs of various reductions in the arsenic MCLs in public water systems of various sizes, the number of users of each public water system, and the expected reductions in counts of bladder and lung cancer, they seek advice about the value of the reduced cancer mortality and morbidity. These values are generated by a) reductions in treatment costs of cancer and cardiovascular diseases (CVD), b) the value of the loss of years of life associated with cancer and CVD mortality, c) the loss of good health associated with cancer and CVD morbidity, d) the reduction in uncertainty about getting cancer or CVD in the future, and e) possible other issues such as avoiding reductions in children's IQ which has found to be associated with high concentrations of arsenic (Wasserman et al, 2014).

This Report provides NHDES with several estimates of the economic value of reducing the MCL allowable in public water systems in NH. After brief considerations of estimates that might be provided by advocates for the sanctity-of-life, by economists using Quality Adjusted Life Years to maximize the effects of budgetary expenditures, and by juries compensating for lives lost, this Project updates literature-reported estimates of the economic value of lowering arsenic levels in drinking water and summarizes the results of recent survey of NH residents designed to estimate of the economic value of lowering the arsenic MCL in public water systems throughout the State. Specifically in November 2018, this research asked 500 NH households connected to either municipal or public water systems about their willingness to add to their monthly water bill in order to lower the chances they might get cancer because of arsenic in their water. This research then uses the observed NH average this willingness to pay for two purposes. First NHDES can compare that willingness to add to their water bill to pay for reducing the probability of bladder and lung cancer against the annualized per-household cost of bringing each non-compliant public water system into compliance. Second, this project uses this willingness to pay to calculate a NH Value of a Statistical Life (VSL). This Report proceeds by applying the NH VSL to arsenic-caused CVD to calculate an additional value of reducing the arsenic MCL, Finally, the Report draws

from the literature to place a value on improvements in childhood IQ that may be associated with reductions in water-born arsenic.

II. ALTERNATIVE METHODS FOR ESTIMATING THE VALUE OF LIFE

Just one of the four fundamentally different ways of estimating the value of life is most applicable to estimating the economic value of reducing the arsenic MCL. Those who oppose abortion and euthanasia often rely on a belief in the sanctity of life, which is the first of the four options. Health economists look at payments for medical treatments and the consequential improvements in health outcomes to estimate the cost of a Quality Adjusted Life Year (QALY). Juries use statistics about a person's expected lifetime incomes to compensate for an injury or death. Most applicable to reducing arsenic in public water, environmentalists compare willingness-to-pay for reductions in the likelihood of contracting and/or dying from cancer to calculate a value of a statistical life (VSL).

Value Based on the Sanctity of Life

Since 1995, conservative members of Congress have made several attempts to introduce a "Sanctity of Life Act" (2011) in order to establish rights of personhood for all human life beginning from conception. An implication of such legislation is that recognition of the sanctity of life can apply to policy decisions and allow a near infinite valuation on the amount that may be spent on protecting from any risk of death. Although the phrase "sanctity-of-life" plays an important role in both political and academic arenas, its meaning and origin are unclear. Baranzke (2012) offers "a reconstruction of the history of the idea of sanctity-of-life." She suggests that "sanctity" should not be understood as an ontological feature of biological human life implying an infinite value. Instead, the idea can be better understood as the sense of "sanctifying" one's life by living it in a special spirit. "Thus, the phrase denotes a *mode of acting* instead of an obscure *property* of physical life."

Quality Adjusted Life Years

Once the sanctity-of-life's infinite value is set aside as idealistic but incapable of guiding budget decisions, three empirical and market-based approaches remain. For more than two decades, health economists have used a $50,000 per QALY benchmark for the value of care (Neumann et al. 2014). By definition, the QALY measure weights the expected additional life-years associated by any improvements in treatment by the quality or health status of each of those additional life-years. As an example, one additional QALY may be obtained by EITHER one expected additional year of life at perfect health OR two expected additional years of life at 50% of perfect health.

When comparing published cost-effectiveness analyses published in the 1990s with those published between 2010 and 2012, the proportion of studies that added a $100,000 per QALY jumped from 10.2% to 40.6% (Neumann et al. 2014). Even more recently, the Institute for Clinical and Economic Review, a private, non-profit US organization reporting the value of drugs and other technologies, has been calculating new prescription "value prices" using thresholds of $100,000 and $150,000 per QALY (Neumann and Cohen, 2017).

While the cost-per-QALY approach makes no distinction on the threshold level by age, using a cost-per-QALY approach does make the value of any savings proportional to the age of the patient-beneficiary. So, for example,

Neonatal Intensive Care Units are typically judged cost-effective because their extremely costly efforts to save infants born prematurely are offset by the babies that go on live full lives. The problem with the cost-per-QALY approach is that it only evaluates the extent to which individual treatments (or public health programs) have incremental effects that more than justify the incremental treatment costs. Cost-effectiveness analysis is an inappropriate method to estimate the value of reducing the arsenic MCL because it provides no insight into people's willingness to pay to avoid the possibility of diseases entirely.

Jury Awards

Juries provide an alternative estimate of the value of lives lost or injuries incurred. Unfortunately, the authors have been unable to access any statistical compilation of jury awards. Some examples include

- www.delawareonline.com/story/money/2016/12/21/jury-orders-dupont-pay-2m-c8-case/95710838/
  - 2016 Jury orders DuPont to pay compensatory damages of $2,000,000 in C-8 Case []
  - In October 2015, Carla Bartlett, a West Virginia resident who claimed C-8 exposure is responsible for her kidney cancer, was awarded $1.6 million in compensatory damages
- www.delawareonline.com/story/money/2016/10/19/dupont-face-10-c-8-trials-three-months/92414412/
  - Three cases have been resolved. Last year, Carla Bartlett was awarded $1.6 million after a federal jury concluded C-8 exposure was responsible for her kidney cancer. A second case, brought by West Virginia resident John M. Wolf, was settled for an undisclosed amount. In the third lawsuit, a jury awarded David Freeman of Washington County, Ohio, $5.6 million in punitive and compensatory damages. DuPont is appealing the Bartlett and Freeman cases.
- slaterzurz.com/women-say-growing-decades-long-evidence-shows-talc-causes-ovarian-cancer/
  - In just the past four years, Johnson & Johnson, renowned for its Baby Powder, has been hit with more than $700 million in jury awards regarding this issue. At present, some 4,800 women have filed suits against the company, which has lost six of the seven cases decided so far in courts spanning from the east to the west coast.
  - With the most recent – and most shocking – jury award to date in this controversy, Johnson & Johnson was ordered to pay $417 million to a California woman named Eva Echeverria, because they failed to warn about the potential risks of using their products containing talcum powder. At 63 years old, Echeverria is terminally ill with ovarian cancer and in critical condition at the time of her trial, was too ill to testify.
  - In May of this year, a jury in St. Louis, Missouri agreed to award $110 million to Lois Slemp, who at age 62 was battling both ovarian and liver cancer, and was too ill to attend her own trial. She

claimed her 40-plus years of using baby powder contributed directly to her cancers, and pointed to lab results showing asbestos particles found inside her body. She was diagnosed with ovarian cancer in 2012, which subsequently spread to her liver.

- www.nytimes.com/2018/07/12/business/johnson-johnson-talcum-powder.html
  - Johnson & Johnson was ordered Thursday to pay $4.69 billion to 22 women and their families who had claimed that asbestos in the company's talcum powder products caused them to develop ovarian cancer.
  - A jury in a Missouri circuit court awarded $4.14 billion in punitive damages and $550 million in compensatory damages to the women, who had accused the company of failing to warn them about cancer risks associated with its baby and body powders.
  - The first talc trial was in 2013 in Federal District Court in South Dakota. A jury found Johnson & Johnson negligent but did not award damages to the plaintiff. Several other cases have involved sizable damages, including a $417 million verdict reached by jurors in Los Angeles County Superior Court last year.

Value of a Statistical Life

When looking at risk/reward trade-offs that people make with regard to their health, environmental economists often consider people's willingness to pay for specific risk reductions and the resulting value of a statistical life (VSL). VSLs are calculated based on observed willingness to pay for small reductions in morbidity or mortality risks. For example, when conducting a cost-benefit analysis of new environmental policies, the EPA uses estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution. The VSL is the dollar value that an individual places on a small change in their probability of death multiplied by the inverse of that probability.

Robinson and Hammitt (2015) provide an accessible (non-technical) description of methodologies used to derive VSLs along with a description of how academics and regulatory agencies synthesize the results of disparate studies to arrive at a central value of VSL used for policy purposes. VSL estimates are based on an estimate of the amount that an individual is willing to pay (WTP) for a small reduction in the risk of mortality or illness within a defined period of time. As Robinson and Hammitt describe, this WTP estimate can then be aggregated into VSL: "if an individual is willing to pay $900 for a 1 in 10,000 risk of dying in the current year, his VSL is $9.0 million ($900 WTP ÷ 1/10,000 risk change)."

Deriving VSL therefore depends on obtaining accurate estimates of how much individuals would be willing to pay to avoid risk of mortality. To obtain such estimates, economists use either revealed preference (generally hedonic wage studies) or stated preference (survey-based studies using contingent valuation or choice experiments) techniques. Revealed preference studies use market data to infer a "price" to risk reduction. For example, a revealed preference study might estimate the "risk premium" associated with wages earned for performing hazardous work. Stated preference techniques, like contingent valuation or choice experiments, rely

on surveys. Contingent valuation methods directly ask respondents about their willingness to pay for reduction in risk. Choice experiments allow respondent to rank different hypothetical scenarios or outcomes, where each scenario is associated with a particular cost or payout and a particular risk.

Selecting the appropriate VSL values for a particular policy question is challenging. Existing studies will yield a wide range of results, depending on the year of the research and the methodology used to derive WTP estimates. Generally, very few studies will apply directly to the arsenic MCL policy change in question. VSL might differ by age cohort or the specifics of the risk (for example illness versus trauma). Furthermore, WTP is generally measured for an immediate risk (e.g. willingness to pay to avoid increased mortality this year), but lung and bladder cancer and cardiovascular disease are associated with latency: illness develops only years after exposure.

The remaining sections of this Report focus entirely on VSL estimates of the economic value of reducing the arsenic MCL in NH municipal water supplies. The next section, Section III, reviews the literature about the value of reducing the arsenic MCL and adjusts those previously published value estimates to current US dollars. Section IV outlines the methods and results of our double-bounded dichotomous choice survey data collected during November 2018.

III. REVIEW OF THE LITERATURE

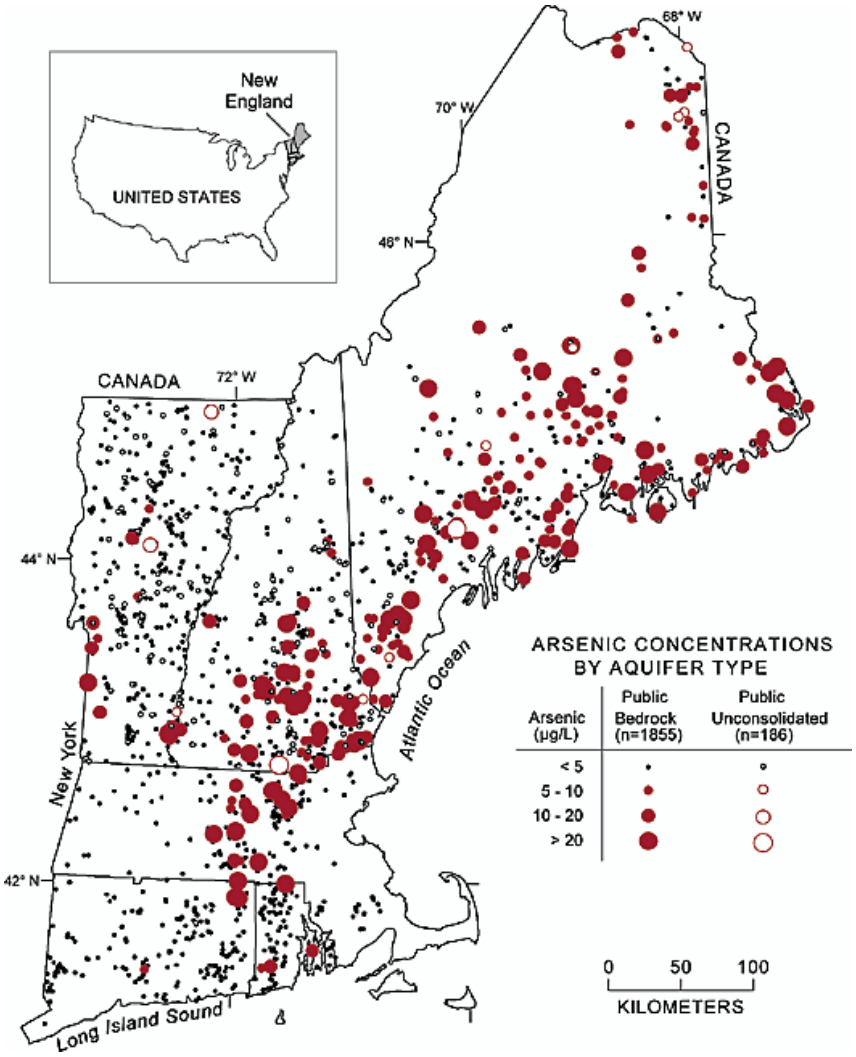
Arsenic in Drinking Water[1]

Occurrence and Exposure.

Arsenic is a naturally occurring element present in the environment in both organic and inorganic forms. Inorganic arsenic, the more toxic form, is found in ground water, surface water, and many foods. US EPA has classified arsenic as a Group A human carcinogen, based on sufficient evidence from human data. Arsenic can combine with other elements to form inorganic and organic arsenicals. Erosion and weathering of rocks releases arsenic into groundwater and water bodies and can lead to uptake of arsenic by animals and plants. Arsenic can also enter ground and surface water from industrial sources. Consumption of food and water are the major sources of arsenic exposure for U.S. citizens, but via inhalation and dermal contact may also pose risk. Some regions of the country have more naturally occurring Arsenic in drinking water. New England, and New Hampshire specifically (see Figure 1), has elevated levels of naturally occurring arsenic in its groundwater (Welch et al. 2000).

Figure 1. Arsenic in Groundwater in New England: Occurrence, Controls, and Human Health Implications. Source: Ayotte et al. 2017.

[1] This section is principally devoted to summarizing the results of the Abt (2000) report which formed the basis for the cost/benefit analysis used by USEPA in formulating their arsenic rules.



Health Effects.

Exposure to arsenic has many potential health effects (NRC, 1999; ATSDR, 1998). Ingestion of inorganic arsenic can result in both cancer and non-cancer health effects. The nature of the health effects avoided by reducing arsenic levels in drinking water is a function of characteristics unique to each individual and the level and timing of exposure.

A National Research Council report states that epidemiological studies show clear associations with several internal cancers at concentrations of several hundred ppb of drinking water (NRC, 1999). Increased mortality from multiple internal organ cancers (liver, kidney, lung, bladder, nasal, and prostate) and increased incidence of skin cancer were observed in populations consuming drinking water high in inorganic arsenic (EPA, IRIS web site

extracted 8/99; Tsai et al. 1999). Increased lung cancer mortality has been observed in multiple human populations exposed primarily through inhalation. Noncancerous effects on cardiovascular, pulmonary, immunological, neurological, endocrine, reproductive, and developmental systems have also been noted (NRC, 1999). Until relatively recently, research on arsenic exposure and its health effects has only been able to quantify scientifically defensible risks for bladder, lung, and skin cancer. A large study published in 2015 (D'Ippoliti, et al.) enables quantification of increased risk of cardiovascular disease associated with a wide range of arsenic levels. These newly quantified risks are included in this Report.

In addition to the general risk from arsenic, various groups are particularly susceptible. These include: children**,** because their dose of arsenic per unit of body weight will be, on average, higher than that of adults exposed to similar concentrations due to their higher fluid and food intake relative to body weight; pregnant and lactating women because of the adverse reproductive and developmental effects of arsenic; people with poor nutritional status; and individuals with pre- existing diseases that affect specific organs, because these organs act to detoxify arsenic in the body.

Cognitive Effects.

Exposure to industrial chemicals has been linked to injuries of the developing (i.e. child's) brain. These developmental disabilities include autism, attention-deficit hyperactivity disorder, dyslexia, and other cognitive impairments. Grandjean and Landrigan (2014) identified five key industrial chemicals as developmental neurotoxicants: lead, methylmercury, polychlorinated biphenyls, arsenic, and toluene. These disabilities can diminish quality of life, reduce academic achievement, and disturb behavior, with profound consequences for productivity. They note that the "developing human brain is uniquely vulnerable to toxic chemical exposures, and major windows of developmental vulnerability occur in utero and during infancy and early childhood. During these sensitive life stages, chemicals can cause permanent brain injury at low levels of exposure that would have little or no adverse effect in an adult" (Grandjean and Landrigan, 2014: 330). Regarding arsenic specifically, exposures to inorganic arsenic from drinking water are associated with cognitive deficits which are apparent at school age (Wasserman et al. 2007; Hamadani et al. 2011). Loss of cognitive skills reduces children's academic and economic attainments; Bellanger et al. (2013) estimate that each loss of one IQ point decreases average lifetime earnings capacity by about €12,000 or $18,000 US in 2008 dollars (adjusting by the CPI, this is equivalent to in $21,565 US dollars). Since IQ losses are part of developmental neurotoxicity, the total costs are likely higher.

Studies focusing on the neurotoxicity effects of arsenic in drinking water are few compared with elements like lead and mercury. Tsuji et al. (2015) conducted a review and risk assessment on possible neurodevelopmental effects at lower arsenic exposures. They note that "the overall evidence supporting a causative association of arsenic exposure at low doses with neurodevelopmental effects in humans is relatively weak" (Tsuji et al. 2015: 102), and that the most rigorously conducted studies in Bangladesh report statistically significant associations of total arsenic in blood (Wasserman et al., 2011) and concurrent speciated arsenic in urine (Hamadani et al., 2011) with lower raw verbal IQ score in children age 5 years and older. Although Wasserman et al., 2004, Wasserman et al., 2007 found significant associations of poorer performance, processing speed, and full-scale raw IQ scores (but not verbal IQ) with arsenic in water, but not in urine (total arsenic analysis) or blood" so that the correlation

between arsenic and IQ is not firmly established. They note that it is problematic comparing Bangladesh to U.S. exposure since there are more routes of exposure in Bangladesh as well as differences in study methods.

Probably of more use for the New Hampshire case is the study by Wasserman et al. (2014) "A cross-sectional study of well water arsenic and child IQ in Maine schoolchildren." The authors studied 272 children in grades 3–5 from three Maine school districts, to determine if there was an association between drinking water arsenic and intelligence (as measured by WISC-IV, the Wechsler Intelligence Scale for Children-Fourth Edition). They concluded that consumption of well water arsenic was associated with decreased scores on most WISC-IV Indices, even after adjustment for other socioeconomic factors. The authors compared children with exposure to drinking water arsenic levels < 5 ppb to those exposed to arsenic levels ≥ 5 ppb, and found reductions of approximately 5–6 points in IQ. They conclude that "The magnitude of the association between WAs [drinking water arsenic] and child IQ raises the possibility that levels of WAs ≥ 5 ppb, levels that are not uncommon in the United States, pose a threat to child development" (Wasserman et al. 2014: p. 13). Their conclusions were qualified due to the small sample size (which may have hindered finding associations). Also, when trying to reconcile the Maine results with previous studies in Bangladesh, there was a lack of "high-end" exposures in the Maine sample, and fewer "low-end" exposures in Bangladesh, making comparisons difficult. Finally, there was a lack of information on quantity of water consumed, and the authors were unable to characterize arsenic exposure retrospectively across the lifespan of the population studied.

Wasserman et al. (2014) conclude that the 5 ppb may represent an important threshold. The strength of associations in the Maine study was similar to those observed with modest increases in blood lead, an established risk factor for diminished IQ.

Economic Impacts of Reducing Arsenic Exposure

Prior to establishing the current arsenic standard, the EPA conducted a benefits analysis (EPA, 2000) for lowered arsenic levels, which included feedback from its Science Advisory Board (SAB, 2000). The EPA report relied on a cost-benefit analysis commissioned by USEPA from Abt Associates (Abt, 2000). The primary benefit of reduced arsenic levels, as quantified in the Abt-EPA's analysis, was the reduced risk of bladder and lung cancer mortality and morbidity. They calculated the benefits of reduced mortality in monetary terms using estimates of the value of a statistical life (VSL) applied to each reduction in mortality. This sub-section of our Report first reviews the findings from Abt and EPA, reports how these values have developed since 2001, and then applies the same methodology as used in the EPA study to analyze potential alternatives to the current MCL for the State of New Hampshire.

The Abt-EPA Report Abt (2000) report noted the existence of estimates of VSL that ranged from $0.7 million to $16.3 million with a mean of $4.8 million (in 1990 dollars). They observed the values were sensitive to differences in population characteristics and to perception of risks. Based on their analysis of 26 different economic studies, the EPA ultimately elected to use a value of $6.1 million (in May 1999 dollars) per statistical life.

For morbidity reductions, the EPA would ideally have estimated the willingness to pay (WTP) to avoid treatable, non-fatal cancer. Since such data were unavailable, the EPA used WTP to avoid chronic bronchitis as a surrogate

for the willingness to pay to avoid cancer. Their valuation was based on a 1991 study by Viscusi et al. The EPA selected a valuation of $607,162 (in May1999 dollars) per case of morbidity avoided.

The EPA's overall benefits estimate was just the sum of valuations for mortality and morbidity. The low end estimate of 6.6 mortality cases and 18.9 morbidity cases for bladder cancer corresponded to an economic benefit of: $6.6 * \$6{,}100{,}000 + 18.8 * \$607{,}162 = \$51.7 \text{ million}$. This corresponded closely to the low-end value that EPA reported for annual bladder cancer cases avoided: $52.0-$113.3 million dollars (EPA, 2000; pg.5-26, in Exhibit 5-11).[2] After aggregating benefits of reductions in both bladder and lung cancer the EPA estimated total health benefits of reducing the MCL for arsenic from 50 ppb to 5 ppb to be in the range of $191.1-$355.5 million dollars in 1999 dollars. The EPA noted that this estimate excludes many non-quantifiable health benefits.

The EPA also noted six considerations that might generally affect VSL and WTP estimates they used to estimate lung and bladder cancer benefits from reducing the arsenic content in drinking water:

1. *A possible "cancer premium" (i.e., the additional value or sum that people may be willing to pay to avoid the experiences of dread, pain and suffering, and diminished quality of life associated with cancer-related illness and ultimate fatality);*
2. *The willingness of people to pay more over time to avoid mortality risk as their income rises;*
3. *A possible premium for accepting involuntary risks as opposed to voluntary assumed risks;*
4. *The greater risk aversion of the general population compared to the workers in the wage risk valuation studies;*
5. *"Altruism" or the willingness of people to pay more to reduce risk in other sectors of the population; and*
6. *A consideration of health status and life years remaining at the time of premature mortality.* (EPA, 2000; pg 2-23).

In addition to these six concerns the Science Advisory Board report (SAB, 2000) also notes that latency, the time lag between the ingestion of arsenic and the onset of cancer, may also affect VSL estimates.

To account for concerns about latency as well as points (2) and (3) from the list above (income effects and involuntary risks), the EPA adds a sensitivity analysis to its central estimate of $6.1 million for the VSL. Using a 3% discount factor, a 10 year latency period, and a range of income elasticities between .22 and 1.0 produces a VSL in the $5.0-$5.4 million dollar range (EPA 2000, pg 5-30; Exhibit 5-12). In other words, long latency periods will lower the estimated benefits for cancer cases avoided to an extent that is not easily offset by factors like a higher WTP associated with income or a higher WTP to avoid involuntary risk.

Based on Abt's analysis along with EPA's own report, in 2001 the US EPA issued regulations revising the arsenic drinking water standard and clarifying compliance and new-source contaminants monitoring provisions (EPA 2001a; 66 FR 6976) which established a health-based, non-enforceable MCLG for arsenic of 0 mg/L and an enforceable MCL for arsenic of 0.01 mg/L (*i.e.,* 10 micrograms per liter [µg/L]) for both community water systems (CWSs) and non-transient non-community water systems (NTNCWSs). As part of the arsenic regulation,

[2] The EPA report did not explain the $300,000 discrepancy between the calculated value and the one reported in the table. It is possible that the VSL of $6.1 reported on page 5-23 is rounded and that a slightly higher value is used in the derivations used in Exhibit 5-11.

EPA also listed approved analytical methods to measure compliance as well as the Best Available Technologies (BATs), small system technologies that could achieve compliance with the MCL, consumer confidence report requirements for CWSs, and public notification requirements for public water.

Comparing and Updating Published Values of VSL

In order to select a value for VSL, analysts typically begin with a survey of the literature to identify high-quality underlying studies. The analyst must choose inclusion criteria like the study date and methodology. For example, in its 2001 Benefits Analysis, the EPA uses 26 wage studies to arrive at a central value of $6.1 million (May 1999 dollars) for VSL. While the EPA continues to use these same studies in its 2014 guidance on estimating benefits, relying exclusively on that figure for the purposes of this report would overlook newer studies that provide updated information on VSL. For example, because WTP to avoid mortality risk is likely to be a "normal" good, meaning that as real incomes rise individuals will be willing to pay more to avoid risk, more recent studies are likely to show a higher willingness to pay for mortality risk reduction.

We consider three sources for guidance on the appropriate value for VSL: EPA guidelines for cost-benefit analysis which were published in 2010 and updated in 2014 a study by Viscusi that provides a "best practice" meta-analysis of recent VSL estimates, and a 2011 study by Adamowicz et al. that uses contingent valuation and choice experiment methods to elicit WTP valuations specifically for reduced risk of bladder cancer in municipal drinking water in Canada.

The EPA central estimate is taken from the 2014 update on its "Guidelines for Economic Analysis." The EPA uses 26 estimates of VSL, mostly derived from studies published in the 1980's and 1990's, to recommend a central estimate for VSL of $7.4 million in 2006 dollars, which is equivalent to about $9.2 million in 2018. In its documentation of this estimate, the EPA notes that it may be appropriate to adjust this figure to account for the timing of risk by adjusting WTP estimates to account for higher future income levels and to discount risks that occur with a lag (EPA, 2014, appendix B).

Viscusi (2013) offers a recent assessment of the VSL literature. The author studies whether publication bias affects the types of VSL estimates accepted for publication, and therefore the magnitude of the central estimate of VSL used by government agencies like the EPA. Although Viscusi finds that publication bias exists, "recent policy applications of the VSL by [the Department of Transportation and] other federal agencies also have been in the general range of the publication bias-corrected value of VSL." (p. 49). After correcting for publication bias, Viscusi produces estimates of VSL that range from 7.6 to 13.7 million dollars in 2013 dollars, with the author's preferred specifications producing estimates below $11 million.

The study by Adamowicz et al. (2011) is particularly relevant to this review since it focuses specifically on the risk of arsenic in municipal water supplies. Like the New Hampshire results presented later in this report, Adamowicz et al. (2011) rely on the use of survey questions to elicit valuations. Their focus is on how respondents prioritize mitigating different types of risk (bacterial contaminants v. arsenic). Adamowicz et al. (2011) present several estimates of VSL, and derive estimates for the value of a statistical life that range from $14 to $17 million Canadian dollars (2004C$). These values represent a lower bound on the VSL for cancer risk reduction, since they do not account for latency. In other words, the values represent what respondents would pay, at the time

of the survey, to avoid cancer risk years away. Adding reasonable discount rates and assuming latency period of 15 years or longer implies valuations above $20 million (2004C$). This valuation adjusted for latency is near the top of the range of values typically found in the literature on VSL. Unlike the figures drawn from EPA or Viscusi, the valuations in Adamowicz et al. (2011) are the results of a single study rather than central estimates of a broader literature.

After converting the estimates from Adamowicz et al. (2011) to U.S. dollars and using the CPI to update all values to June 2018 dollars, the pertinent values of VSL are:

Table 1: VSL in 2018 Dollars

Study	VSL in June 2018 Dollars (millions)
Adamowicz et al, 2011	13.7-16.6
EPA, 2014	9.2
Viscusi, 2013	8.2 to 14.8

Economic Value of Reducing Arsenic MCL on Cancer Mortality in NH

Tables 2 and 3 present two estimates of cancer deaths avoided due to more stringent arsenic standards. These calculated deaths avoided are based on estimates of the number of cancer deaths attributable to arsenic ingestion given different standards. Staff at NHDES estimate the figures in Table 2 using the cancer target organ risk estimates in the NRC document, "Arsenic in Drinking Water 2001 Update" (National Research Council, 2001). A second set of estimates for the number of cancer deaths attributable to arsenic ingestion, which NHDES uses as the basis for Table 3, are derived from target organ cancer risk estimates in two 2017 Lynch et al. journal articles (Lynch et al, 2017a, Lynch et al, 2017b). NHDES converts risk estimates to expected cancer deaths using the percentage of lung and bladder cancer cases in NH that result in death as reported in the tables "New Cancer Cases per 100,000 Rank" and "Cancer Deaths per 100,000 Rank" in the publication New Hampshire Cancer Report Card, authored by the NH Department of Health and Human Services, Office of Health Statistics and Data Management (NH Department of Health and Human Services, April 2009). The percentages of cancer cases that result in death were then applied to the estimates of cancer cases in the population served by NH community water systems.

Table 2:
Estimated Bladder and Lung Cancer Cases and Deaths over a 70-Year Averaging Period Due to Arsenic Exposure from NH Public Water Systems Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified Maximum Contaminant Levels
(Risk coefficients based on NRC, 2001)

Assumed MCL (ppb)	Total Cancer Cases	Non-Fatal Cancer Cases	Total Deaths	
			Lung	Bladder
10	101	55	37	9
6	89	49	32	8
5	82	44	30	8
4	75	41	27	7
3	66	36	24	6

Table 3:
Estimated Bladder and Lung Cancer Cases and Deaths over a 70-Year Averaging Period Due to Arsenic Exposure from NH Public Water Systems Based on Recent Arsenic Testing Results (2014-2017) and Assuming Specified Maximum Contaminant Levels
(Risk coefficients based on Lynch et al, 2017a and 2017b)

Assumed MCL (ppb)	Total Cancer Cases	Non-Fatal Cancer Cases	Total Deaths	
			Lung	Bladder
10	33	13	19	1
6	28	11	16	1
5	27	10	16	1
4	25	10	14	1
3	22	8	13	1

In order to identify a value for the benefits of reducing the maximum contaminant level for Arsenic, we multiply estimates for the number of lives saved, as provided by NH-DES and described above, by VSL values of 8.2

million, 10.1 million and 13.7 million. These values, respectively represent the low-end of the reasonable values identified by Viscusi et al., the policy guidance of the EPA and a value based on a single study relevant to this specific issue.

Table 4:
Literature-Based VSL Estimates of the Economic Value Derived from Avoiding Lung and Bladder Cancer Deaths Over a 70-year Period.

MCL (ppb)	Deaths Avoided (Table 2)	Deaths Avoided (Table 3)	VSL low ($8.2 mil)	VSL medium ($9.2 mil)	VSL high ($13.7 mil)
10	0	0			
6	6	3	$24.6 - $49.2	$27.6 - $55.2	$41.1 - $82.2
5	8	3	$24.6 - $65.6	$27.6 - $73.6	$41.1 - $109.6
4	12	5	$41.0 - $98.4	$46.0 - $110.4	$68.5 - $164.4
3	16	6	$49.2 - $131.2	$55.2 - $147.2	$82.2 - $219.2

Perhaps the most striking feature of Table 4, is the degree of variation: across rows, across columns, and within cells. The variation across rows reflects the expected result that increased stringency results in fewer deaths and therefore higher benefits. It is noteworthy that the estimated number of avoided deaths is small in absolute terms, making it hard to estimate the incremental benefits of small changes in the arsenic standard. The variation across columns reflects the fact that economic studies find a range of values for VSL: all three of the values used here are in the range of consensus estimates from the economics literature. Within the range of VSL's reported here, the range of uncertainty over benefit valuations appears driven more by scientific uncertainty about the health impacts of arsenic than the economic uncertainty over the central value estimate of VSL. Later in this Report, we summarize the results our own survey of NH public water users to provide guidance about which of these values might be most appropriate for NH.

Economic Impact of Reducing Arsenic MCL on Cancer Morbidity in NH

For morbidity reductions, the EPA would ideally would have liked to estimate of the willingness to pay (WTP) to avoid treatable, non-fatal cancer. Since such data were unavailable, the EPA used WTP to avoid chronic bronchitis as a surrogate for the wiliness to pay to avoid cancer. Their valuation was based on a 1991 study by Viscusi et al. The EPA used a valuation of $607,162 (in May1999 dollars) per case of morbidity avoided.

We also estimate the benefit of non-fatal bladder and lung cancer cases avoided using two valuations: the value of $607,162 (in May1999 dollars) per case of morbidity avoided, which the EPA used in its 2001 report and the WTP estimate derived from Adamowicz et al. (2011). The latter specifically measures estimates of the value of statistical illness (VSI) for cancer cases caused by arsenic, finding values that fall between C$2.9 and C$4.1 million (2004C$), with a central estimated value of $3.3 mil, which assumes a latency spread evenly over 35 years. Converting the 3.3 million dollar valuation to US dollars[3] and then adjusting both the $607,162 and the 3.3 million dollar valuations to September 2018 dollars yields respective valuations of: $922,210 and $3.38 million. This wide range reflects the fact that the literature on estimating the value of illness avoided is less developed, and less prone to consensus, than the illness on VSL.

Table 5:
Literature-Based Estimates of the Economic Value Derived from Avoiding Non-Fatal Lung and Bladder Cancer Cases Over a 70-year Period.

Assumed MCL (ppb)	Non-Fatal Cases Avoided (Table 2)	Non-Fatal Cases Avoided (Table 3)	EPA Value Per Case Avoided: $922,210 in 9/18 dollars (in millions)	Adamowicz Value Per Case Avoided $3.38 million in 9/18 dollars (in millions)
10	0	0		
6	6	2	$1.8 - $5.5	$6.8 - $20.3
5	11	3	$2.8 - $10.1	$10.1 - $37.2
4	14	3	$2.8 - $12.9	$10.1 - $47.3
3	19	5	$4.6 - $17.5	$16.9 - $64.2

Economic Impact of Reducing Arsenic-Related Cardiovascular Disease

The NHDES estimate that the annual deaths from arsenic-related cardiovascular disease per 10,000 exposed population is 19 at 10 arsenic ppb and 12 deaths per 10,000 people at 3 arsenic ppb. Using a table of Current Arsenic for Public and Commercial Water Systems provided by the NHDES, there are 215 public water systems reporting arsenic ppb above 3. These public water systems serve 54,434 people. The average person in this cohort has 5.483 ppb of arsenic in their water. Presuming that the number of deaths avoided changes linearly from 10 ppb to 3 ppb, reducing the arsenic from 5.483 ppb to 3 ppb would save 517 lives per 10,000 people over

[3] We use the 2004 annual average exchange rate of 1.301 Canadian dollars per USD, suggesting a valuation of 2.53 USD ($2004).

70 years, or 2814 of the 54,434 citizens. Applying the literature VSL values, an enforced MCL of 3 in public water systems would have an economic value of between $4.2 billion and $7.1 billion, Table 6.

Table 6:
Literature-Based VSL Estimates of the Economic Value Derived from Avoiding Cardiovascular Deaths Over a 70-year Period

MCL (ppb)	Deaths per 10,000 Avoided over 70 yrs	VSL low ($8.2 mil)	VSL medium ($9.2 mil)	VSL high ($13.7 mil)
10	0			
Avg 5.483	813	$4.2 bil	$4.8 bil	$7.1 bil
3	1,330			

Economic Impact of Higher IQs Associated with Lowering the Arsenic MCL

Starting with the assumption that the diminished IQ caused in children exposed to arsenic in drinking water ranges from 5 to 6 points, we can use estimates derived from similar studies (especially those which studied the effects of lead on IQ levels) to determine the cost on a per case basis of this change over a lifetime. In a study of the costs of lead exposure to children 1-5 years old, Gould (2009), drawing on estimates developed by Salkever (1995), Schwartz (1994), and Nevin et al. (2008), calculated that a loss of one IQ point presents a loss of $17,815 in present discounted value of lifetime earnings (in 2006 US dollars; in 2018, this equates to $22,719 when adjusted by the CPI). In a study of the effects of mercury emissions on IQ, Griffiths et al. (2007) suggest a loss of 4% of lifetime earnings from a decrease in IQ of one point. With their assumption of $472,465 (in year 2000 U.S. dollars), this equates to $18,899 ($28,313 in 2018 CPI-adjusted dollars). Bellanger et al. (2013) estimate that each loss of one IQ point decreases average lifetime earnings capacity by about €12,000 or $18,000 US in 2008 dollars (adjusting by the CPI, this is equivalent to in $21,565 US dollars). Of course, the net present value of lifetime lost earnings due to reduced IQ is a function of the discount rate chosen (commonly 5% in the studies noted), and there is an implicit assumption of linearity between IQ reduction and income loss. Thus, there can be a substantial range of valuation estimates based not only on interest rates but on the country where the IQ loss occurs and other factors; for example, Bellanger et al.'s (2013) found a range of €7,529 – 20,220 across the countries in their study.

Considering the total potential impact of lowered IQ from drinking water arsenic in New Hampshire, we need to use an estimate of children exposed to various levels of arsenic by age. If we use the 5 ppb level suggested by Wasserman et al. (2014) as a threshold, there are 23,540 New Hampshire residents exposed to community water systems with >5 ppb arsenic. Since we do not have the age profile of these households, we used U.S.

Census demographic averages to determine that 24.7%, or about 5,814 children age 19 and younger are exposed to water systems >5ppb arsenic. Since the definition of "vulnerable" in the literature varies—i.e. the studies use different age groups for their analyses—we can further use census data to estimate that 5.3% of New Hampshire residents are 5 years old or less, so 5.3% of 23.540 yields an estimate of 1,248 children exposed to > 5ppb arsenic in their drinking water; this percentage increases to 11.2% for residents 9 years old or less, or 2,636 of the 23,540. Using the estimate for children less than 5 years old (since this is more prevalent in the literature) gives a loss of lifetime earnings for a one point decrease in IQ which ranges from $21,565 to $28,313. A summary of the lifetime income losses due to a reduction of 5.5 points in IQ (midpoint of Wasserman et al.'s Maine study) is provided in Table 7. Note that the estimate for range of lost income due to decreased IQ assumes that ***all*** children 5 years and under exposed to the 5 ppb arsenic level suffer the full IQ reduction. However, given the caveats mentioned earlier (e.g. small sample size, one study based on Maine, lack of information on tap water consumed, etc.) these estimates of net benefits from reduction of arsenic ingestion on the affected populations should be treated with caution until further epidemiological evidence is available.

Table 7:
Selected Valuation Estimates for loss of IQ Points on Lifetime Earnings

Study	Basis of Valuation	Estimated Lifetime Earnings Loss caused by Decrease of 1 IQ Point	Estimated Lifetime Earnings Loss caused by Decrease of 5.5 IQ Points
Bellanger et al. (2013)	Estimates of Health Effects of Mercury Exposure in European Countries	$21,565	$118,607.5
Gould (2009)	Summary of Previous Studies on Lead Exposure in U.S.	$22,719	$124,954.5
Griffiths, McGartland, and Miller (2007)	Update of Estimates of Health Effects of Mercury Exposure in U.S.	$28,313	$155,721.5
Potential Range of Lost Income due to Decreased IQ	Empirical Estimates **X** 1,248 Vulnerable Children Exposed	$26,913,120 – 35,334,624	$148,022,160 – 194,340,432

IV. A NH-SPECIFIC ESTIMATE OF RESIDENTS' WILLINGNESS TO PAY FOR ARSENIC FILTRATION THAT WOULD REDUCE THEIR MORBIDITY AND MORTALITY RISKS FROM CANCER

Introduction

The objective of this analysis is to assess the welfare consequences of the proposed change to arsenic standards for drinking water in New Hampshire. To do this, we derive a New Hampshire specific value of a statistical life (VSL), which, when coupled with estimates of deaths avoided from the increased water standards, provides a more refined estimate for the benefits of the proposed legislation. This section of the Report details the approach taken in calculating these estimates, emphasizing the data collected and the methodology used in estimation.

This study uses responses from a stated preference survey administered online to 500 New Hampshire residents in which we elicit risk-money tradeoffs for lung and bladder cancer risks from arsenic in drinking water. Our estimates show that, on average, residents who use the community water supply are willing-to-pay $35.50 per month ($426.00 per year) for the reduction in lung and bladder cancer risks associated with lowering the maximum allowable level of arsenic in drinking water from 10 ppb to 3 ppb. Using these estimates, we derive a NH specific VSL of $5,050,813.

Survey Design and Sample

Our examination of estimates of VSL for bladder and lung cancer risks are derived from a stated-preference survey administered online, in which respondents reveal their valuation for a policy that reduces the maximum allowable level of arsenic in community drinking water systems, thus reducing their risk of cancer associated with exposure to the chemical over the lifetime. In this design, we follow the related literature by using iterative choice approach involving a series of two decisions which elicit information on respondent's willingness-to-pay for policies that would reduce risks associated with arsenic in drinking water.

Survey Structure

The survey questionnaire consists of five sections: (1) a cover letter explaining the background for the new arsenic rule, (2) a series of questions that elicit respondents' perceptions about arsenic risks and self-protection levels, (3) an information sheet, which provides detailed information about risks and a visual representation of these risks via a risk ladder, (4) the contingent valuation questions, which represent a series of questions eliciting respondents' valuations for the proposed increase in water quality, and (5) a series of questions eliciting demographic information. (A copy of the survey can be found in Appendix A1.)

The information sheet in section (3) of the survey explains how the reduction in arsenic concentration levels translates into the reduction in cancer risks, how this risk reduction compares to more common risks, and current and historical arsenic concentration levels throughout the state. This information sheet is intended to help reduce respondents' information gaps with respect to the health consequences of arsenic and is expected

to provide a more certain response to the valuation questions presented in section (4). The risk information presented in the information sheet of section (3) was presented in frequency format with a population denominator. Specifically, the survey characterized incidence levels in terms of the risk out of populations of 10,000, and made this number more salient by linking it to the town of Conway, New Hampshire, which has a population of about 10,000 residents.

The contingent valuation questions of section (4) in the survey elicit respondent's willingness-to-pay (WTP) to lower the maximum allowable level of arsenic in community water systems. As this survey is sampling both municipal water systems users, as well as community well users, we felt it appropriate to frame the valuation question in terms of their monthly WTP for use of a hypothetical water filtration system which would allow them to achieve the new water quality standard. Specifically, we asked the following WTP question in the survey:

> *Assume there is a water treatment system that could be used to reduce the level of arsenic in your water to 3ppb and thus increase the quality of your drinking water. Would you be willing to pay $_____ per month for use of this water filtration system?*

Following the well-established double-bounded dichotomous-choice contingent valuation procedure, we use 5 initial bid amounts and a set of follow-up bids contingent upon their response to the initial valuation question (in parentheses): $5 ($2.50/$10), $10 ($5/$20), $20 ($10/$40), $40 ($20/$80), $80 ($40/$160).[4] If the respondent answered "yes" to the initial valuation question, the follow-up question presented a value that was exactly double that of the first, and if they responded "no" to the initial valuation question, they are presented with a follow-up value exactly half of the initial bid.

Sample Description

The data for this analysis comes from a double-bounded, dichotomous choice (DBDC) contingent valuation study administered to a cross-section of municipal water system and community well users across New Hampshire and was conducted in November of 2018. The total sample size for this analysis is 500 and these responses were gathered online via a sample purchased through the UNH Survey Center using the Qualtrics Survey Suite. An email was sent to potential respondents with a link to follow to access the survey. This sample described below includes respondents who (1) were over 18 years old, (2) received their tap water from the community water supply, i.e. municipal water system or community well, and (3) consumed at least 25% of their drinking water from the household tap.

Table 8 presents summary statistics for the survey used in this analysis. The characteristics of the sample reasonably followed the distribution of the state of New Hampshire. Specifically, this survey represents a higher portion of females than the NH state average (66.7% vs. 50.5%) the average age in the sample was slightly older, (45.0 vs. 42.4), household income slightly lower ($63,291 vs. $70,936), and the number of respondents with a

[4] The median bid amount ($20) is based on a cost estimate from the $1,200 per household per year to lower the maximum allowable level of arsenic to the proposed level (3ppb), repaid over 5 years, and was supplied by the NHDES.

bachelors' degree or more slightly higher (47.9% vs. 45.3%). Further, the location of respondents matches closely the distribution of the population throughout the state, by county. In terms of current self-protection mechanisms, roughly half (49.7%) of the respondents in this sample use some form of home drinking water filtration, i.e. a Brita or other filtration system. Finally, the majority (78.2%) of respondents felt there were none to minor health concerns associated with drinking their tap water.

Empirical Methodology

To generate welfare estimates (i.e. individual's' willingness-to-pay) for the proposed improvement in drinking water quality from reduced arsenic levels, we rely on the double-bounded dichotomous choice data collected from section (4) of the survey described above. The welfare estimates from this analysis can be interpreted as the "individual willingness-to-pay for a reduction of arsenic in municipal drinking water from 10ppb to 3ppb." To calculate these, we first use the bivariate probit model of Cameron and Quiggin (1994) which assumes that respondents express two WTP values and accounts for the fact that the initial bid my act as a reference, in that it may influence their evaluation and thus responses to the follow-up bid. The underlying WTP values are modeled as:

$$WTP_{i1} = x_{i1}\beta_1 + \epsilon_{i1}$$

$$WTP_{i2} = x_{i2}\beta_2 + \epsilon_{i2} \qquad (1)$$

where x_i represent a vector of explanatory variables, including respondent demographics, measures of household size, levels of self-protection, and current town-level arsenic levels, WTP_{i1} and WTP_{i2} are the *i*th individual's willingness-to-pay in the first and second questions, respectively. Here, ϵ_{i1} and ϵ_{i2} are error terms following a bivariate normal distribution and assumed correlated, thus capturing any starting-point effects to this methodology. (Alberini, 1995) To describe variations in WTP responses across individuals, the explanatory variables (x_i) to be used in this estimation procedure include current levels of self-protection (i.e. use of water filter or water filtration system in the home), bid amounts, respondent age, education, gender, income, household size, the presence of a child in the house, perceptions of arsenic exposure risk, as well as a measure of the current arsenic exposure per respondent which is a weighted-average of arsenic concentrations at the town level.

The value of a statistical life (VSL) is interpreted as the rate at which individuals are prepared to trade off income for risk reductions. Using the NHDES' preliminary 70-year (bladder and lung) cancer death risk estimate, reducing the level of arsenic in drinking water from 10ppb to 3ppb translates to a reduction in the risk of death from cancer of 0.0024 (0.0034 vs. 0.0010). An NH-specific VSL is estimated using the yearly WTP derived from the survey above, and is calculated as $[(\frac{WTP}{\frac{0.0024}{70}}) \div 2.46]$, where the denominator $(\frac{0.0024}{70})$ represents the cumulative risk reduction and this is then divided by the average household size in the state (2.46) to represent the VSL for each individual in the household. These VSL estimates are of course sensitive to derived measures of WTP for the cancer risk reductions, so robustness checks will be performed to determine sensitivity of these estimates to model specifications.

Results

Table 9 presents a set of results of the estimation described above. Here, we present three models whose results are used to derive estimates of a VSL. Model 1 is parsimonious, in that it only models the choices of responses based on the bids. Model 2 adds an additional set of demographic controls, including gender, age, education, household income, household size, and the presence of a child in the home. Model 3 further controls for a measure of self-protection (i.e. current use of a water filtration system), perceptions of risk associated with tap water, and current arsenic exposure[5] and serves as the preferred model for this analysis as it is the model that most strongly fits the data sample.

The bottom three rows of Table 9 present monthly and yearly willingness-to-pay estimates for the proposed reduction in arsenic and the subsequent VSL estimates derived using those welfare measures. Monthly WTP is calculated by multiplying each of the coefficients in the model by their mean value in the sample and summing across these coefficients. Across the three models, respondents are willing-to-pay, on average, $34.21-$35.50 per month for the reduction in bladder and lung cancer risk associated with the reduction in arsenic in drinking water from 10 ppb to 3 ppb. This translates to yearly WTP estimates of $410.52 to $426.00 for the same reduction.

Using these estimates and the method described above to derive undiscounted VSLs, Model 1 estimates a VSL of $4,875,813. By adding demographic controls via Model 2, that VSL decreases slightly to $4,867,276. Finally, in Model 3, after controlling for current self-protection measures, we see an increase in the VSL to $5,050,813. This can be explained by the fact that those who currently use some form of self-protection are more likely to pick the proposed water treatment option, which involves higher costs and lower risks, consistent with their current behavior. That is, currently using some form of a water filtration system involves higher costs associated with purchasing the system and lower risks associated with the consumption of filtered water.

But the willingness to pay over a 70 year period would involve cash payments far enough into the future to have their present value be affected by discounting. Discounting to a present value converts the annual payments into an amount, which if deposited in a bank at the specified interest rate, would be exactly enough to make all the annual payments and have exactly nothing left after the last payment. Without discounting, Model 3 specifies a VSL of $5.050 million. At a 1% and a 3% annual discount, that VSL is reduced to $3,656 million and $2.164 million respectively.

[5] Current arsenic exposure is controlled for by including a dummy variable ("High As Exposure") which indicates if the respondent lives in a town with current As readings greater than 3ppb.

Table 8.
Demographic Summary Statistics

	Sample Mean	NH Mean*
Female	66.7%	50.5%
Age	45.0	42.4
Annual HH Income	$63,291	$70,936
Education (% BA+)	47.9%	45.3%
Child in Household	37.5%	30.5%
Location		
Belknap	4.9%	4.6%
Carroll	5.4%	3.6%
Cheshire	5.8%	5.8%
Coos	3.1%	2.4%
Grafton	6.1%	6.7%
Hillsborough	34.1%	30.5%
Merrimack	10.9%	11.1%
Rockingham	17.5%	22.5%
Strafford	9.2%	9.4%
Sullivan	3.1%	3.3%
Health Concern		
None	45.8%	
Minor	32.4%	
Moderate	14.9%	
Serious	7.0%	
Home Filter	49.7%	

Notes: New Hampshire means are derived from the US Census American Fact Finder System: https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

Table 9.
Bivariate Probit Estimates of Contingent Valuation Study and Derived Welfare Measures

	Model 1	Model 2	Model3
Constant	34.271***	-30.905	-17.103
	(2.518)	(38.806)	(38.672)
Female (Yes = 1)		-5.717	-5.159
		(5.565)	(5.515)
Age		-0.386*	-0.303
		(0.187)	(0.184)
Bachelors+ (Yes = 1)		-6.332	-3.734
		(5.488)	(5.429)
ln (HH Income)		8.950*	4.918
		(3.725)	(3.735)
Child in HH (Yes = 1)		7.423*	6.778
		(3.476)	(3.459)
Household Size		-4.649	-3.510
		(2.745)	(2.714)
Health Concern			6.229*
			(2.824)
Home Filter (Yes = 1)			21.100***
			(5.189)
High As Exposure			9.616
			(8.257)
Log likelihood	-783.6543	-75.6422	-761.7074
N	500	499	499
WTP (Monthly)	$34.27	$34.21	$35.50
WTP (Yearly)	$411.24	$410.52	$426.00
VSL (no discount)	$4,875,813	$4,867,276	$5,050,813
VSL (1% discount/yr)	$3,529,406	$3,523,227	$3,656,081
VSL (3% discount/yr)	$2,089,434	$2,085,776	$2,164,467

Notes: Numbers in parentheses are standard errors. *, **, *** indicate statistical significance at the 0.10, 0.05, and 0.01 levels, respectively.

V. SUMMARY AND CONCLUSIONS

This Report provides NHDES with literature-based and a NH-survey-based estimates of the economic value of reducing the arsenic maximum contaminant level (MCL) allowable in public water systems in NH. The Report considers the benefits of reducing the MCL from 10 parts per billion (ppb) to 3 ppb and includes reductions in

morbidity and mortality from lung and bladder cancers, reductions in cardiovascular disease mortality, and improvements in children's IQ.

Literature Updates

Values of Statistical Life (VSL) from three sources (Table 1), when updated to June 2018 dollars, range from $8.2 million to $14.8 million. When applying these VSLs to the NHDES-provided deaths that might be avoided by lowering the arsenic MCL from 10 ppb to 3 ppb, calculations of the resulting economic value range from $24.6 million to $219.2 million. When applying updated EPA and Adamowicz values for each non-fatal lung and bladder case avoided, lowering the arsenic MCL from 10 ppb to 3 ppb is associated with an economic value of between $4.6 million and $64.2 million.

Although, in their year 2000 analyses, EPA and Abt Associates lacked sufficient scientific evidence to estimate economic values for either the reduction in Cardiovascular Disease (CVD) or for mitigating the developmental impact of arsenic on children, new scientific evidence allows preliminary estimates for valuing these benefits. When applying the three VSL values to the NHDES-provided estimate for deaths from arsenic-related CVD, lowering the arsenic MCL to 3 ppb is associated with an economic value between $4.2 billion and $7.1 billion. Applying three recent estimates of the economic value of children's IQ points to the expected loss of IQ among children exposed to arsenic above 5 ppb, the economic value of reducing the arsenic MCL to 3 ppb ranges from $26.9 million to $194.3 million. Taken together, these economic values total between $4.256 billion and $7.605 billion.

The largest components of benefits are those from avoided deaths due to CVD and the developmental impacts on arsenic on children. Cardiovascular disease is more common than cancer, so even a small change in incidence of CVD would suggest a significant number of deaths avoided. Despite the fact that the single study associating arsenic to IQ for schoolchildren in Maine does not quantify a specific dose-response effect (Wasserman, 2014), it does find, and this Report incorporates, an overall average effect for all children living in areas with arsenic above 5 ppb. While the scientific consensus on the relationships between a) CVD and arsenic and b) the neurological development of children and arsenic is still emerging, it is beyond the scope of this Report to assess the certainty or confidence intervals around the number of deaths avoided from CVD in New Hampshire or the extent to which arsenic developmentally affects children.

NH Survey of Willingness to Pay to Reduce Cancer Risks

One major caveat to these updated literature-based estimates of economic value is the uncertainty associated with applying geographically and chronologically distant observations to NH in the present. We addressed this concern by conducting an Internet-based survey of 500 NH households connected to public water supplies. This study uses responses from a stated preference survey administered online in which we elicit risk-money tradeoffs for lung and bladder cancer risks from arsenic in drinking water. Our estimates show that, on average, residents who use the community water supply are willing-to-pay (WTP) $35.50 per month ($426.00 per year) for the reduction in lung and bladder cancer risks associated with lowering the maximum allowable level of arsenic in drinking water from 10 ppb to 3 ppb. Using these estimates, we derive a NH specific undiscounted VSL of $5.05 million. At 1% and 3% annual discount rates, these VSLs fall to $3.66 and $2.16 million.

Our own undiscounted measure of VSL is highly similar to the estimated VSL derived from another recent stated preference study on WTP for arsenic reductions in Canada (Adamowicz et al, 2011). When discounted, our VSL values are similar to those used by EPA and many VSL values, often from wage-risk studies, in the literature.

Caveats

As the EPA (2000) has noted, there are a series of considerations that might generally affect WTP and VSL estimates.

1. *A possible "cancer premium" (i.e., the additional value or sum that people may be willing to pay to avoid the experiences of dread, pain and suffering, and diminished quality of life associated with cancer-related illness and ultimate fatality);*
2. *The willingness of people to pay more over time to avoid mortality risk as their income rises;*
3. *A possible premium for accepting involuntary risks as opposed to voluntary assumed risks;*
4. *The greater risk aversion of the general population compared to the workers in the wage risk valuation studies;*
5. *"Altruism" or the willingness of people to pay more to reduce risk in other sectors of the population; and*
6. *A consideration of health status and life years remaining at the time of premature mortality.*

All of these concerns apply equally to our own work as they have to all prior publications that we have updated.

Additionally, a typographical error in the questionnaire distributed to the study participants under-reported the proportional reduction in cancer deaths that could be expected by reducing the arsenic 10 to 3 ppb in drinking water. The distributed questionnaire indicated the reduction from 34 deaths per 10,000 cases to 10 deaths per 10,000 cases was a 50% reduction, when it should have said a 71% reduction. Consequently, the willingness to pay and the VSL values reported in our Table 9 may be biased downward and represent conservative estimates.

Recommendations to NHDES

This report has provided substantial evidence of the substantial economic value of reducing the arsenic concentrations in the drinking water provided by NH public water systems. Using the best-know cancer risk factors, we find our questionnaire respondents are willing to pay $426 per year for a 0.0024 (or 0.24%) reduction in the risk of lung and bladder cancer over a 70 year period. After considering the average 2.46 people in each NH household, that willingness to pay corresponds to a value of a 70-year statistical life of $5.05 million, a number slightly lower than otherwise reported in the literature (Table 1).

Of course, drinking water arsenic has other consequences, even if less well documented. The literature about cardiovascular-related health benefits of lowering arsenic in drinking water suggests benefits that are at least 10 times greater than those derived from lowering cancer cases. In short, the literature relating cardiovascular disease to arsenic suggests that lowering the average arsenic 5.483 ppb reported per person (for all NH individuals with 3 or more ppb) to 3 ppb would avoid 517 deaths over 70 years. Using previously published VSL

estimates, the economic benefit would fall between $4.2 billion and $7.1 billion. Using our VSL of $5.05 million generates an estimated economic benefit of $2.6 billion.

Similarly, the single best published study (Wasserman et al. 2014) relating drinking water arsenic to children's intellectual performance suggests a 5.5 IQ point reduction associated with drinking water arsenic, which when valued at between $26.9 to $35.3 milling in lifetime earnings generates an estimated loss in lifetime earnings between $148.0 and $194.3 million. Of course, earnings over a lifetime differ from willingness to pay. Yet the economic impact of lifetime earnings are typically considered to have a multiplier effect somewhat greater than 1 on any region's overall economy.

We conclude with the hope that NHDES finds these economic value numbers useful as they compare the economic benefits of reducing the required arsenic maximum contaminant levels in public water systems in New Hampshire.

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VI. APPENDIX 1: SURVEY DETAILS

Section 1. Introduction

Arsenic in drinking water is a substantial public health issue in New Hampshire, according to the NH Department of Environmental Services (NHDES). Arsenic occurs naturally in groundwater in New Hampshire, and it has the potential to increase the risk of a wide range of health effects, including bladder and lung cancer. The current regulatory limit of 10 parts per billion (ppb) was chosen by the USEPA in 2000 as a reasonable level at which to balance the risk of harmful health effects with the cost of treating water to remove arsenic in public water systems. A good deal of scientific research has been done since then, which has only served to increase concern about harmful health effects in New Hampshire. In 2018, the NH Legislature directed NHDES to review the federal 10 ppb standard and to determine whether NH should establish a lower level, considering both the benefits and the costs to public water system and their customers.

Our research team from the University of New Hampshire is conducting a survey to gather information on perceptions and preferences related to risks associated with arsenic in residential drinking water in New Hampshire. This survey is funded by the NHDES. In order to participate in this survey, you must be at least 18 years old. This survey will take approximately 10-15 minutes to complete. Survey participation is voluntary and you will not receive any compensation for participating. There are no potential risks for participating in this study.

We seek to maintain the anonymity of all data and records associated with your participation in this research. We will report the data in aggregate, assessing trends in individual preferences and perceptions related to arsenic in drinking water. The results may be used in reports, presentations, and publications.

If you have questions about your rights as a research subject you can contact Melissa McGee at UNH Research Integrity Services at 603-862-2005 or melissa.mcgee@unh.edu. If you have questions about this research project or would like more information, you may contact project leader John Halstead, Professor of Environmental and Resource Economics, University of New Hampshire at 603-862-3914 or john.halstead@unh.edu.

In order for you to help us with this study, you must be at least 18 years old. Are you at least 18 years old?

Yes

No

Do you consume at least 25% of your drinking water from the tap?

Yes

No

How do you receive tap water in your home?

Public or community water supply (incl. community well)

Private well

Section 2. Self-Protection and Perceptions of Safety of Tap Water

This portion of the survey will focus on options for the provision of cleaner and safer drinking water. First, would like some information about the water you drink.

Apart from receiving water from the municipal water utility, what are the other sources of your drinking water? Check all that apply.

Purchased bottle water
Water delivery service
Natural well
Other (please specify) _____
I don't know

What is the source of your tap water? (Select all)

Ground water (e.g. underground water source)
Surface water (e.g. river of lake)
I don't know

How often do you personally drink bottled water that you have purchased?

Never or rarely (once per year)
Occasionally (a couple of times per year)
Sometimes (a couple of times per month)
Frequently (a couple of times per week)
Once per day
Several times per day

How much money do you estimate that your household spends on purchased drinking water (i.e. bottled water) per month?

_____

When purchasing drinking water, you do so mostly because of

convenience.
taste.
health concerns about tap water.

Do you use a home water filtration system of any kind?

Yes
No

How much did your water filtration system cost to purchase? _____

Do you use a container style water filter (e.g. a Brita)?

Yes
No

We would like to get a sense of the percentage of the water you consume from different sources. In the table below, please fill in your best guess of the percentage of water you personally consume from the different sources identified below. (The total from all sources should add to 100%)

Water direct from tap without any home filtering or treating: _____
Home filtered or treated tap water: _____
Purchased drinking water (e.g. bottled water): _____

We would like to know whether you have any health concerns about drinking your tap water. Please choose the one statement that best reflects your personal opinion.

No health concerns. I feel that tap water does not pose a problem for my personal or my family's health.
Minor health concerns. I feel that drinking tap water may pose a minor problem for my personal or my family's health.
Moderate health concern. I feel that drinking tap water may pose a moderate problem for my health or my family's health.
Serious health concern. I feel that drinking tap water may pose a serious problem for my health or my family's health.

Section 3. Health Effects of Arsenic Exposure in Tap Water

One of the benefits of increasing the drinking water standard (i.e. lowering the maximum allowable level of arsenic) in public water systems in New Hampshire is the reduction in the chance of contracting and dying from diseases like lung and bladder cancer. In particular, lowering the level of arsenic in drinking water from 10 ppb to 3 ppb lowers the risk of contracting lung and bladder cancer by 70% and also lowers the risk of dying from those same cancers by 71%.*[6]

To put this in perspective, we have included a visual representation of this risk change in relation to other commonly understood risks. These risks are displayed as a the prevalence of the risk out of 10,000 people. To get a sense of these chances, consider that the town of Conway, New Hampshire has a population of about 10,000 residents.

Please review this graphic carefully before moving on to the next section

[6] Survey participants actually saw 70% and 50% probabilities. This typo in the survey would have reduced their willingness to pay. Consequently their observed willingness to pay, and the VSL calculated therefrom, may be biased downward.

Risk Level		Risk Type		Prevalence (per 10,000)
High		Heart disease by age 70		4,000
		Skin cancer by age 70		2000
Medium		Automobile accident over 20 years (fatal)		280
		Death from opioid overdose over lifetime		91
		Risk of lung or bladder cancer from drinking water with 10 ppb arsenic on a regular basis for 70 years		67
		Audited by the IRS per year		63
		Victim of cybercrime per year		50
		Death from gun assault over lifetime		35
		Risk of **death** from lung or bladder cancer from drinking water 10 ppb arsenic on a regular basis for 70 years		34
		Risk of lung or bladder cancer from drinking water with 3 ppb arsenic on a regular basis for 70 years		20
		Death from fire in home over lifetime		18
		Risk of **death** from lung or bladder cancer from drinking water 3 ppb arsenic on a regular basis for 70 years		10
Low		Death from bicycling accident over lifetime		2
		Risk of cancer from bromate at current drinking water standard of 10 ppb over 70 years		2
		Risk of cancer from vinyl chloride at current drinking water standards of 2 ppb over 70 years		1
		Struck by lightning over lifetime		0.08
		Death from a plane crash over lifetime		0.05

Section 4. Valuation of Health Risk Reductions from Increased Water Quality

We would like to know your opinions about the management of tap water quality in New Hampshire. The following section will ask a series of questions on your willingness-to-pay to increase drinking water quality in New Hampshire, and thus lower your chances of contracting lung and bladder cancer.

Please note, we know that responses from surveys are often not a reliable indication of how people will actually choose. In surveys, some people ignore the sacrifices they would need to make if their choice actually meant they would have less money to spend. We'd like you to respond to the following questions as if this were a real choice -- imagine that you actually have to dig into your pocket and pay the additional charges on your water bill if the majority agreed with your choice. Note that by paying more on your water bill you would have less money to spend on other things.

Assume for a moment that the current level of arsenic in your drinking water is 10 ppb. This is associated with a **67** out of 10,000 chance of eventually getting bladder or lung cancer and a **34** out of 10,000 chance of dying from that cancer due to the arsenic by age 70.

What if a water treatment system could be used to reduce the level of arsenic in your water to 3ppb? This would lower the risk of eventually getting bladder or lung cancer to **20** out of 10,000 and dying from bladder or lung cancer to **10** out of 10,000. Again, this represents a 70% reduction in your chances of getting lung or bladder cancer and a 50% reduction in your chances of dying from that cancer.

Would you be willing to pay $___ per month for use of this water filtration system, which would lower the level of arsenic in your drinking water from 10 ppb to 3 ppb?

Yes

No

Given your response to the question above, would you be willing to pay $___ per month for use of this water filtration system, which would lower the level of arsenic in your drinking water from 10 ppb to 3 ppb?

Yes

No

Section 5. Respondent Demographic Information

What is your gender?
- Male
- Female

What is your current age? _____

How many people live in your household, including yourself?
- 0
- 1
- 2
- 3
- 4
- 5
- 6

How many children under the age of 18 live in your household?
- 0
- 1
- 2
- 3
- 4
- 5
- 6 or more

What is the highest level of schooling you have completed?
- Some high school
- High school
- Some college
- Associates
- Bachelors
- Graduate/Professional

What is your current employment status?
- Student
- Retired
- Full-time
- Part-time
- Self-employed
- Unemployed

What is your approximate annual household income from all sources, before taxes?

- less than $15,000
- $15,000 - $29,999
- $30,000 - $44,999
- $45,000 - $59,999
- $60,000 - $74,999
- $75,000 - $89,999
- more than $90,000

What is your household zip code? _____

Do you have any of the following long-term health conditions?

- Food allergies
- Any other allergies (Please specify) _____
- Asthma
- Arthritis or rheumatism
- Back problems, excluding arthritis
- High blood pressure
- Migraine headaches
- Chronic bronchitis or emphysema
- Sinusitis
- Diabetes
- Epilepsy
- Heart Disease
- Cancer (Please specify type) _____
- Stomach or intestinal ulcers
- Effects of stroke
- Any other long-term condition that has been diagnosed by a health professional (Please specify) _____

In your opinion, how do you think the safety of tap water should be paid for? Check all that apply.

- Increase federal, state, or municipal taxes
- Increase fees to tap water users
- Charge polluters of the water
- Other (please specify) _____