Influence of different water treatment systems on arsenic concentrations in private well groundwater: A view from MDI, ME

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Introduction

Arsenic is a naturally occurring metal classified as a group 1 human carcinogenic substance by the World Health Organization (WHO). Chronic exposure through drinking water has proven to cause cancer in internal organs, damage the cardiovascular and respiratory systems, and tends to lower the IQ of children, thus the federal Environmental Protection Agency (EPA) suggests that the total As concentration in drinking water levels should be lower than **10 µg/L**, the Maximum Contamination Level (MCL), before consumption (EPA, 2001). In Maine, the majority of residents rely on private wells for their water supply, and according to the Maine Center for Disease Control (CDC), around 10% of wells exceed the MCL.

- **Safe Drinking Water Act** states that the government will not regulate private wells that serve less than 25 individuals. It is therefore the responsibility of homeowners to have the water from their private domestic wells tested and treated if necessary (CDC., 2017).

The focus of this study is to evaluate the effectiveness of different water filtration systems (figure 1), currently in use by Maine residents, to filter As and other elements, from private well water (n = 32) in the Mount Desert Island (MDI) area (Figure 2).

Particulate: Designed to capture and remove sand, silt, dirt, and rust from water.

Reverse-Osmosis (R.O.): Filtration membrane with pore sizes <5 nm, designed to filter ions from the water, like arsenic, and uranium.

Water softeners: Aims to filter high concentrations of magnesium and calcium from hard water.

UV treatment system: Reduces and kills bacteria from the drinking water by using UV wavelengths to dissociate the DNA on living cells in the water.

Radon mitigation systems: Radon gas is produced by the breakdown of uranium, which produces lung cancer after chronic exposure. Aeration devices or a Granulated Activated Carbon system are used to mitigate radon.

Figure 1: Different types of filtration systems installed in households of this study.

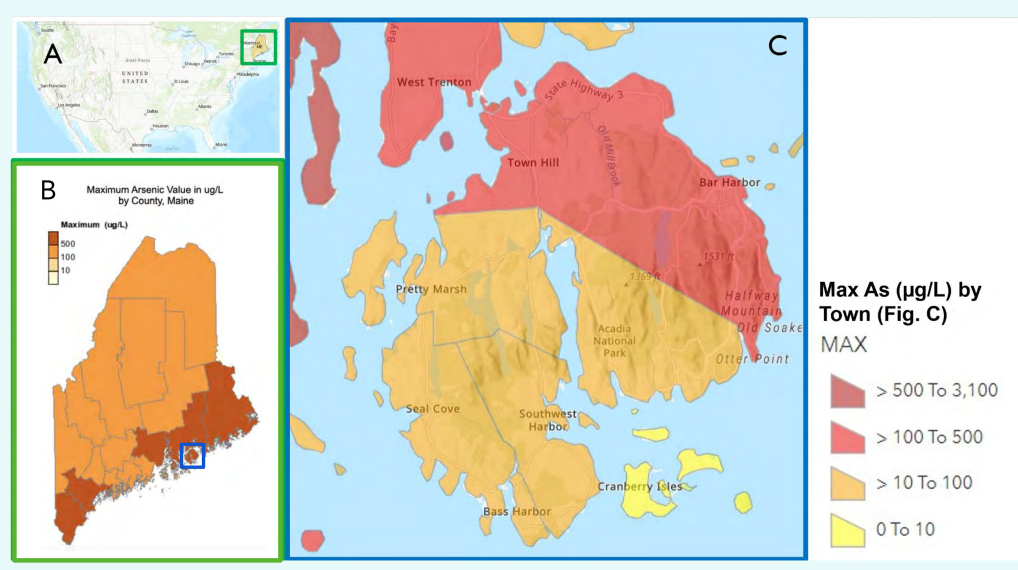


Figure 2: A) Map of the United States B) Map of the state of Maine C) Location of the Mount Desert Island area (Bar Harbor and Mt. Desert, and Trenton) overlain with maximum arsenic concentrations found in private well water (Maine CDC).

Research question

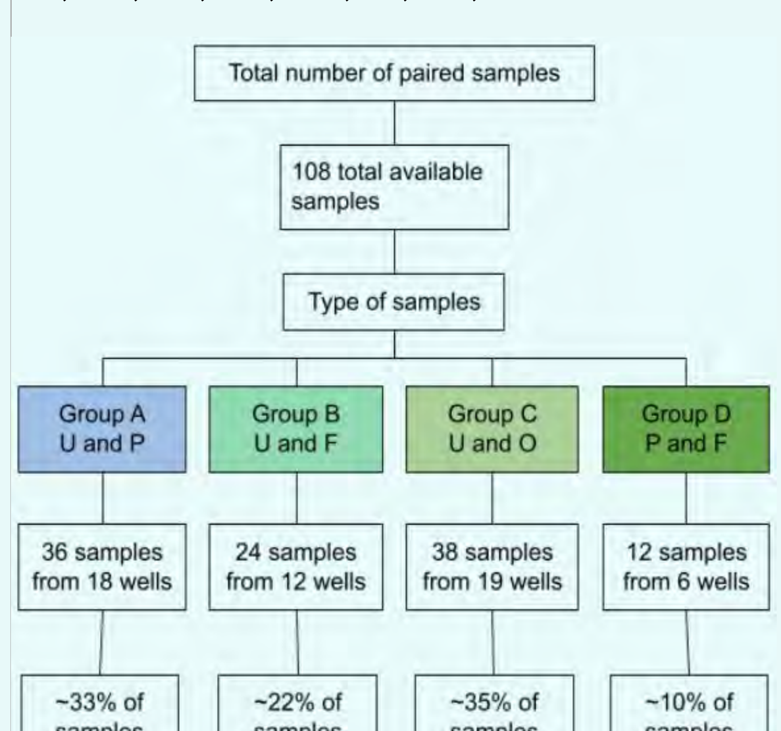
To what extent are different water treatment systems currently in use for private wells in the MDI area working to remove contaminants from the groundwater, specifically the common toxic element, arsenic?

Methods

Paired samples, one unfiltered and one filtered, were collected from 55 private wells in the MDI area during different sampling events:

- **Monthly samples:** (June 2020 - August 2021) 18 private wells, sampling each month.
- **Opportunistic samples:** (2016-2021) 37 private wells, sampled just once.

Samples were sent to the Dartmouth Toxicology Laboratory, where they were analyzed by ICP-MS (inductively coupled plasma-mass-spectrometry) for 14 elemental concentrations: As, Sb, Ba, Be, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Se, and U.



The data falls into 4 groups based on the sample pairings:

- **Group A:** (U) Unfiltered samples and (P) particulate filtered samples
- **Group B:** (U) Unfiltered and (F) samples filtered by R.O. (or other As-removal filters).
- **Group C:** (U) Unfiltered and (O) Other non-As treatment system (water softeners, UV, radon mitigation systems)
- **Group D:** (P) Particulate and (F) filtered samples by R.O. (or other As-removal filters)

Results

Effectiveness of R.O. systems to reduce As for over a year:

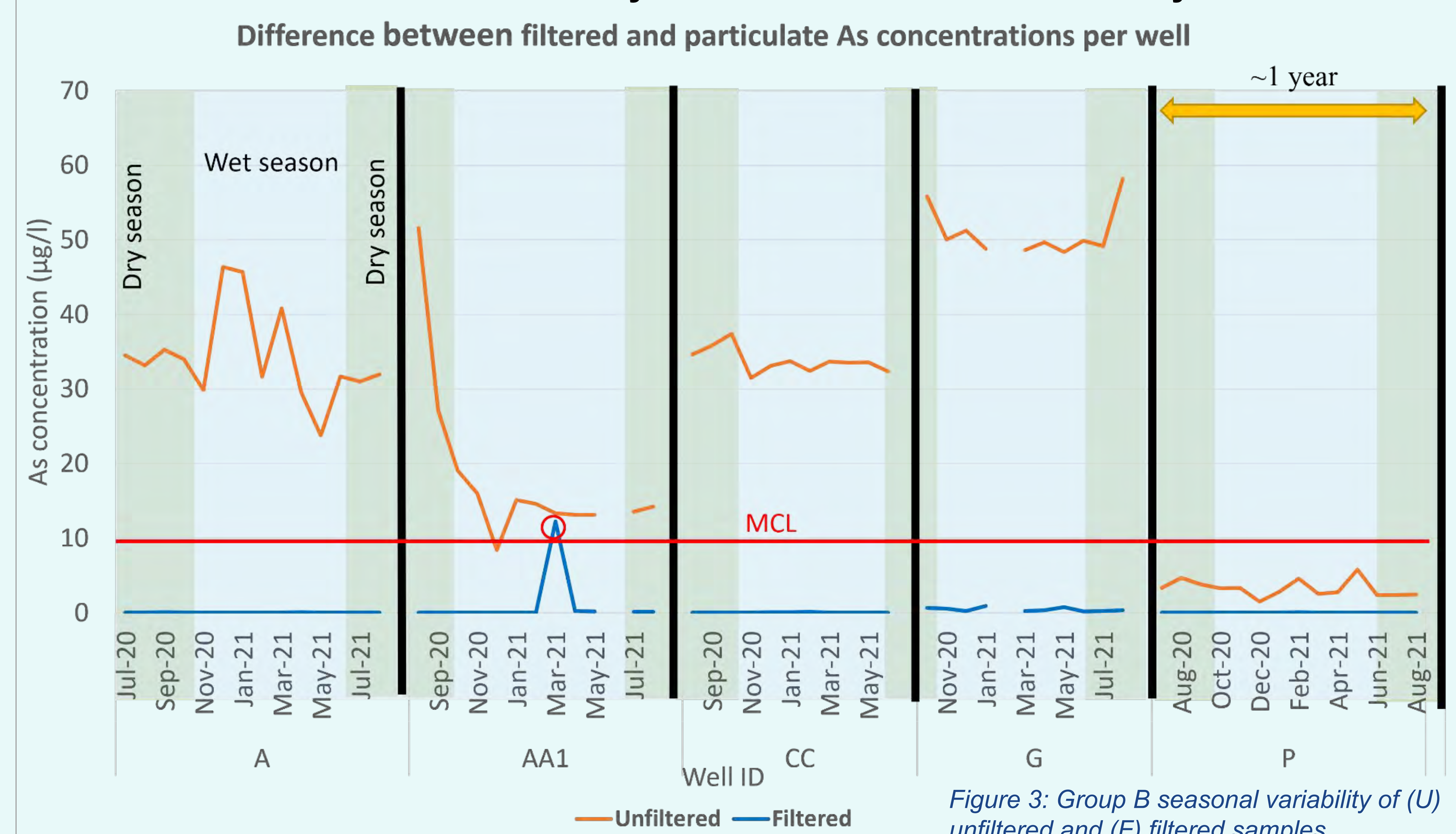


Figure 3: Group B seasonal variability of (U) unfiltered and (F) filtered samples

As concentrations in groundwater fluctuate differently in every well. Well A shows more variability during the wet season, whereas Well CC and P As concentrations stay relatively constant regardless of the season.

Elevated As concentrations (~50 µg/L) in groundwater were successfully reduced by the R.O. system, resulting in filtered water containing levels of As near 0 µg/L.

When maintained properly, R.O. systems effectively reduce As concentrations to safe levels despite seasonal variation in groundwater quality

- *Due to scheduling issues, the availability of some well owners shifted through the monthly program; some wells are missing data for 1 or 2 months causing incomplete lines in figures 3 and 4.*
- *In coastal Maine, the dry season spans from ~June to ~October, and the wet season from ~November to ~May.*

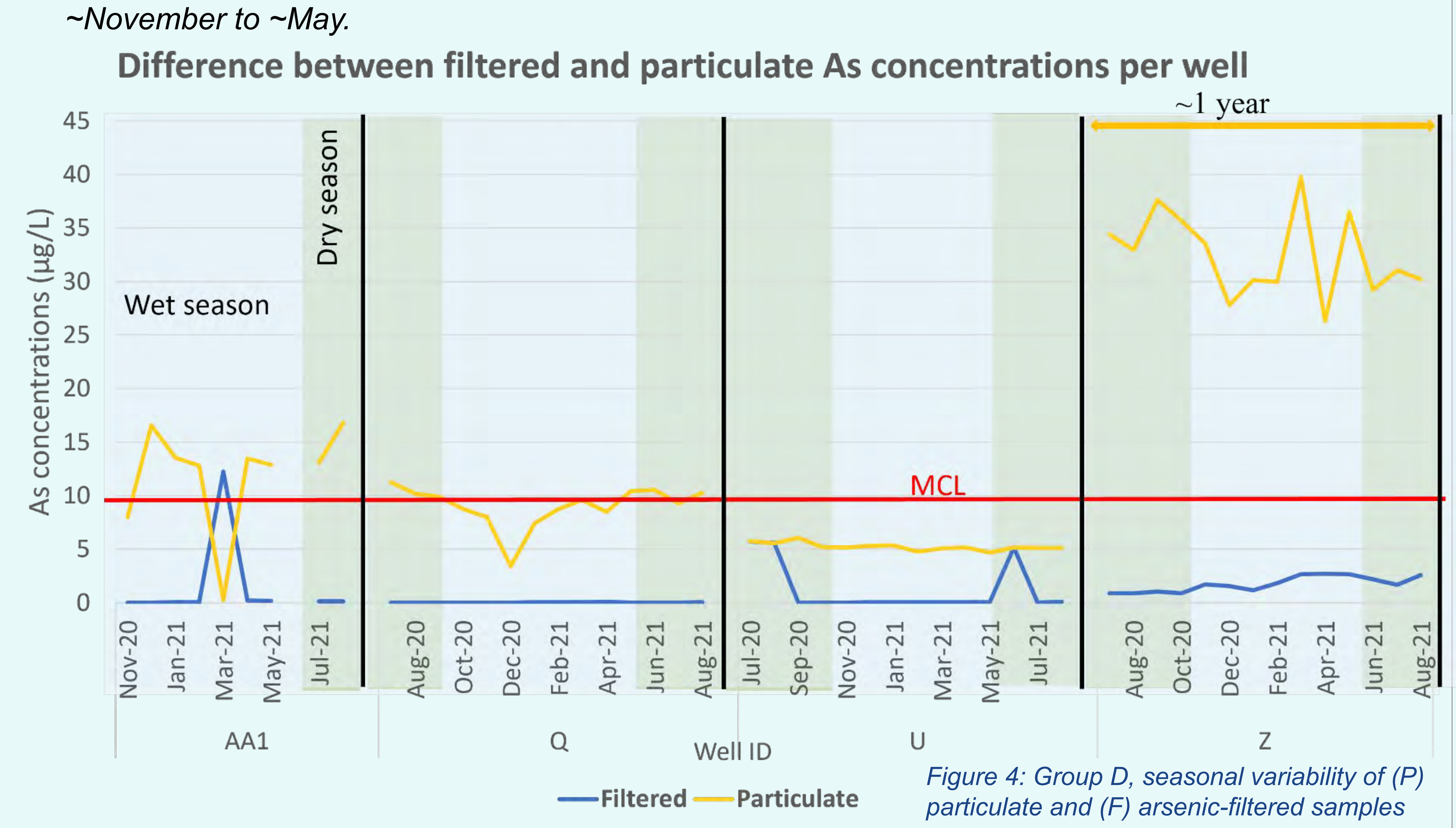


Figure 4: Group D, seasonal variability of (P) particulate and (F) arsenic-filtered samples

Arsenic concentrations post- particulate filter fluctuate as groundwater does, implying that particulate filters alone are unreliable to reduce As to safe levels. Optimistic bias: when the owners' perceived As risks are lower than the real risks, which may lead to the installation of a filter not designed to reduce As, like only a particulate filter.

Well U shows two peaks for R.O. filtered water, at the beginning and at the end of the study. Both peaks were caused because the filter required replacement.

The peak above 10 µg/L in well AA1 in figure 3 reflects a sampling error. This mistake is visualized in this figure 4, where the peak of the R.O. system should, in that month, have the concentrations of the particulate sample instead, and vice versa.

Distribution of concentrations:

Table 1: Summary statistics for As and total element concentration for the different filtration categories

Filtration category	Arsenic unfiltered			Arsenic filtered			Total elements unfiltered		Total elements filtered	
	Mean (µg/L)	Median (µg/L)	Standard deviation	Mean (µg/L)	Median (µg/L)	Standard deviation	Mean (µg/L)	Standard deviation	Mean (µg/L)	Standard deviation
Group A: U and P (n=18 wells)	2.7	1.5	3.6	2.2	0.9	3.1	725	1435	233	202
Group B: U and F (n = 12)	14.7	9.9	15.8	0.3	0.04	0.5	4308	11209	18.2	26.5
Group C: U and O (n = 19)	14.8	0.95	43.6	12.8	0.65	36.8	877	1468	98.5	137

Group A: Well owners with the lowest As concentrations in the groundwater opted for a particulate filter.

- The mean decreased post-filter but experienced the smallest reduction for both As and total concentration.
- Particulate filters remove about a third of the total elements in the groundwater.

Group B: *Well owners with the highest total elemental concentrations have chosen an R.O. system as a treatment system.*

- R.O. systems almost completely reduced the average in both As and total concentration.
- These systems prove to reduced concentrations of As above the MCL to levels near zero.

Group C: *These systems experienced a bigger reduction in As and total concentrations than particulate, but less than R.O.*

- Some water system components such as water softeners are designed to remove elements such as Ca and Mg from the water, not As.

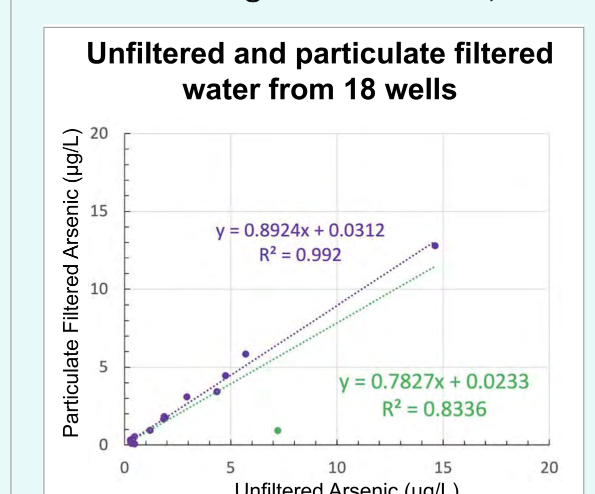


Figure 5: Unfiltered vs Particulate filtered arsenic concentrations. Purple line is linear fit excluding the green outlier point, green line is linear fit with all of the data points.

Reduction of As by particulate filters

- Particulate filters reduced ~10% of arsenic, similar to findings of Ayotte et al. (2003)
- The removed As was likely adsorbed onto fine-grained sediment stopped by the filter.
- How much As is removed by particulate filters is likely dependent on water chemistry and filter maintenance.

Conclusion

Particulate filters may remove ~10% of As, but are not designed to remove all arsenic from the water. Other filters (i.e., water softeners) remove some of the total elemental concentration, but do not reduce arsenic concentrations much more than ~10%.

R.O. systems are an effective way to remove all As and other elements from the groundwater. These systems may fail when not properly maintained.

Regardless of temporal fluctuations in water quality caused by seasonality or intense precipitation events, R.O. systems reliably reduce As in groundwater to near zero µg/L.

While R.O. are great for people who have elevated As, they aren't necessary (or recommended) for all. These systems reduce all elements, deionizing the water from healthy minerals, which leads to adverse consequences (Hoffman, 2022). R.O. water can be mineralized by adding an additional remineralizer water filter or mineral salt into the water

In the future we hope to further investigate how each filtration system impacts the abundance of the other elements analyzed here.

References

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