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Point-of-use drinking water treatment to reduce exposure to aesthetic and health-based contaminants in the Central Appalachian region and surrounding rural communities

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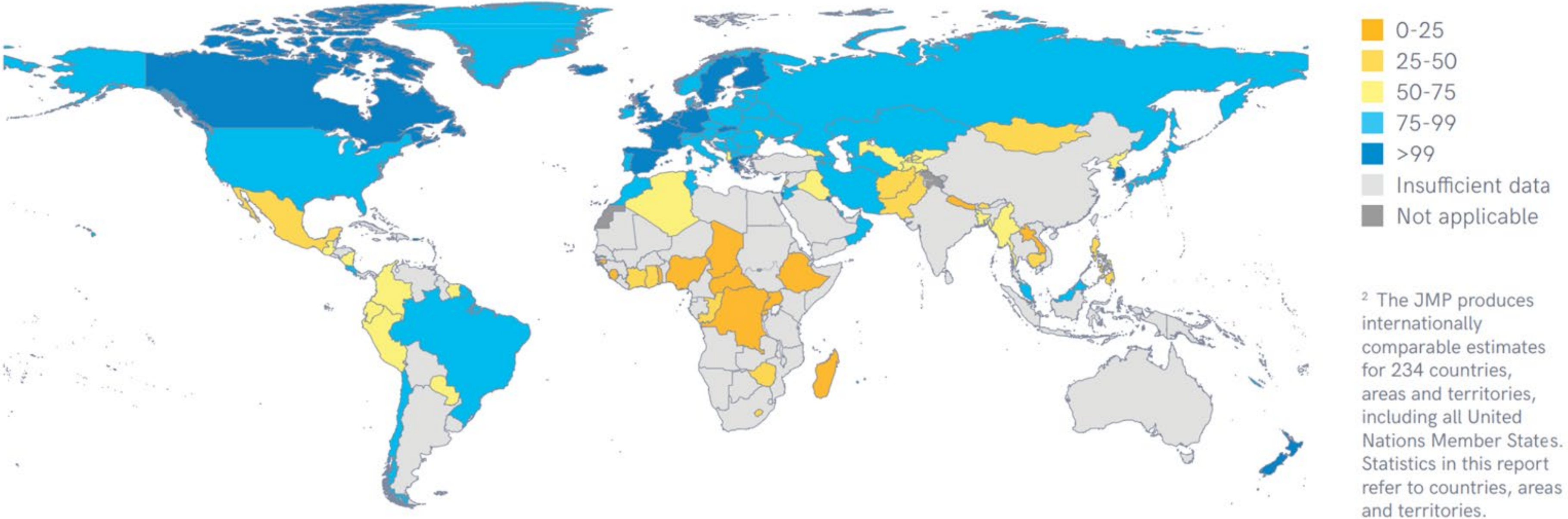
Environmental Engineer

Eastern Research Group, Inc.

November 14, 2023

An estimated 2 billion people worldwide lack access to safely managed drinking water.

In 2020, 138 countries[2] had estimates for safely managed drinking water services



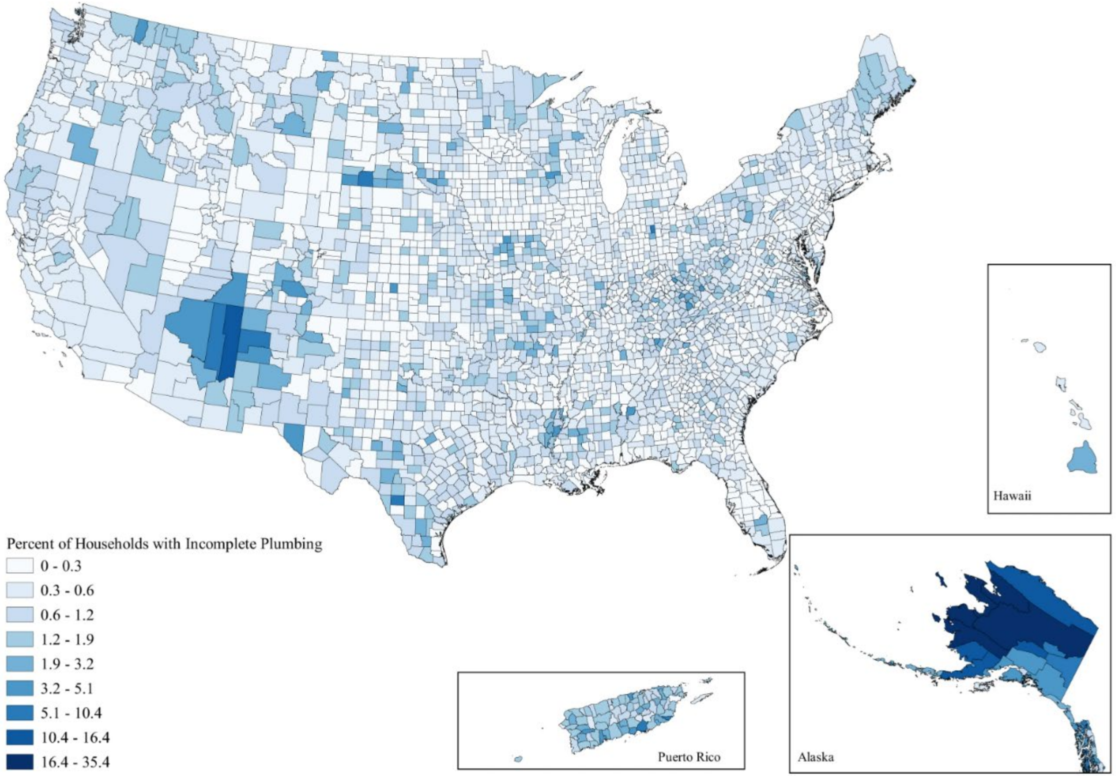
[2] The JMP produces internationally comparable estimates for 234 countries, areas and territories, including all United Nations Member States. Statistics in this report refer to countries, areas and territories.

FIGURE 4 Proportion of population using safely managed drinking water services, 2020 (%)

(JMP, 2021)

Fig. 1: Map of the percent of county households without full indoor plumbing as reported by the 2014–2018 American Community Survey.

From: The widespread and unjust drinking water and clean water crisis in the United States



Households are determined to have incomplete plumbing if they do not have access to hot and cold water, a sink with a faucet, a bath or shower, and—up until 2016—a flush toilet.

(Mueller & Gasteyer, 2021)

Despite near 100% access to safely managed drinking water in the United States, issues of drinking water quality, access, and equity persist.

wtopnews News Traffic Weather

30 years after ruptured pipeline, search for drinking water backup for Potomac River continues

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ENVIRONMENT

NJ sues Dow, others over widespread possible cancer-causing chemical in drinking water

2-minute read

NEWS CHANNEL 13 News Weather 13 Investigates Features Sports

State lawmakers ask for fun lead in drinking water

Dan Levy WNYT
Updated: March 24, 2023 - 12:24 AM
Published: March 23, 2023 - 12:28 PM

CNN health Life, But Better Fitness Food Sleep Mindfulness Relationships

The Kentucky county where the water smells like diesel

By Nadia Kounang, CNN
Updated 5:01 PM EDT, Fri March 30, 2018

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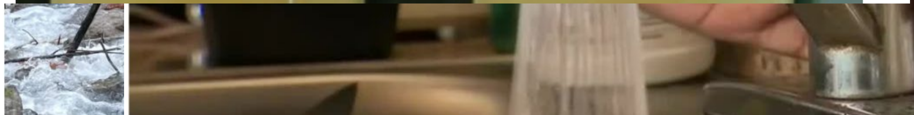
r chemicals' i

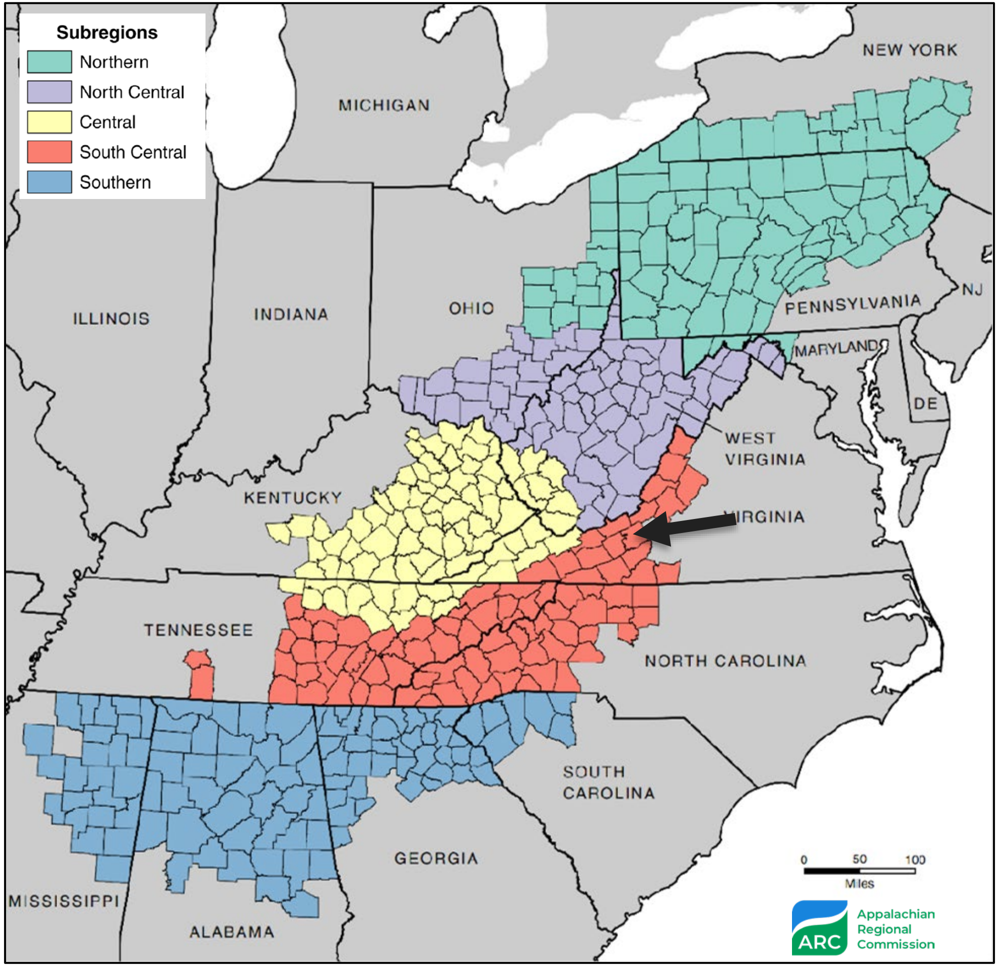
The New York Times

A Water System So Broken That One Pipe Leaks 5 Million Gallons a Day

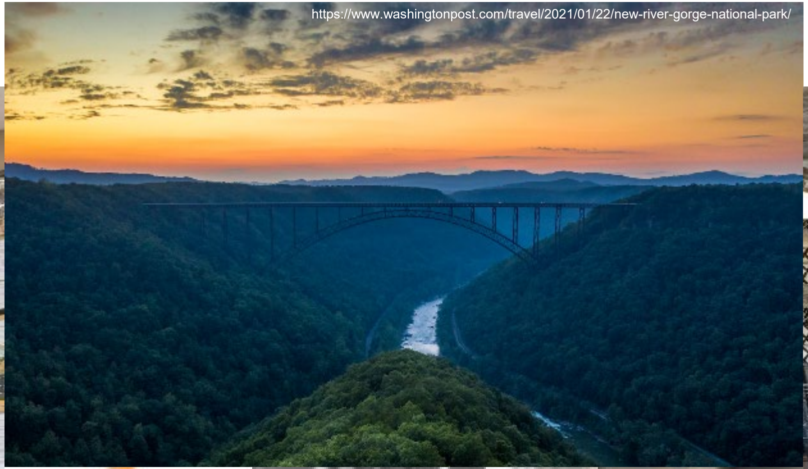
As a water shortage ballooned into a crisis in Jackson, Miss., the leak grew bigger and bigger, gouging out a swimming pool-size crater in the earth.

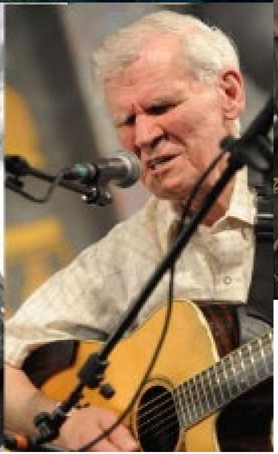


Introduction: Characterizing the Appalachian Region



Introduction: Further Characterizing the Appalachian Region





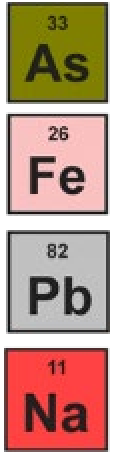
Introduction: Drinking Water Sources & Water Quality Challenges

Community Water Systems

- Regulated by the **Safe Drinking Water Act (SDWA)**
- **Aging, outdated** infrastructure
- Lack of **workforce** and/or **funding**
- Tightened water treatment **standards**

SDWA

- Passed in 1974 to regulate **public** drinking water supplies
- Sets **standards** for contaminants levels and treatment techniques:



  - Maximum Contaminant Levels (MCLs)
  - Secondary Maximum Contaminant Levels (SMCLs)
  - Treatment Techniques (TT)
  - Health Reference Levels/Guidance Levels (HRL/GL)

Introduction: Drinking Water Sources & Water Quality Challenges

McDowell County, WV

Private Well Water Systems

Groundwater systems not regulated by SDWA

No treatment is **required** after initial drilling

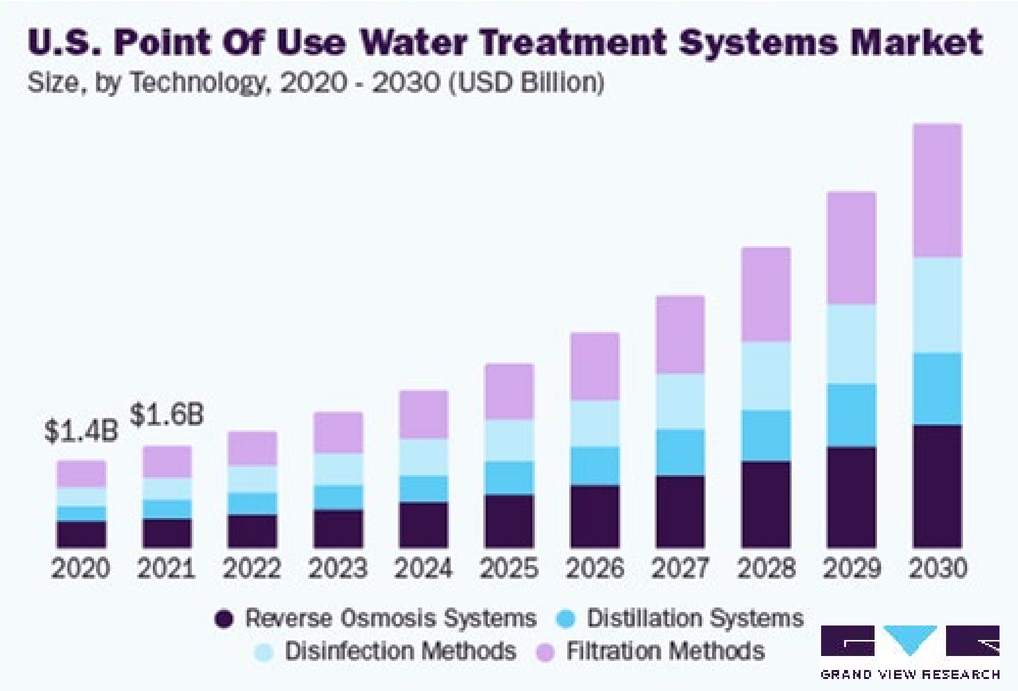
Responsibility of homeowner

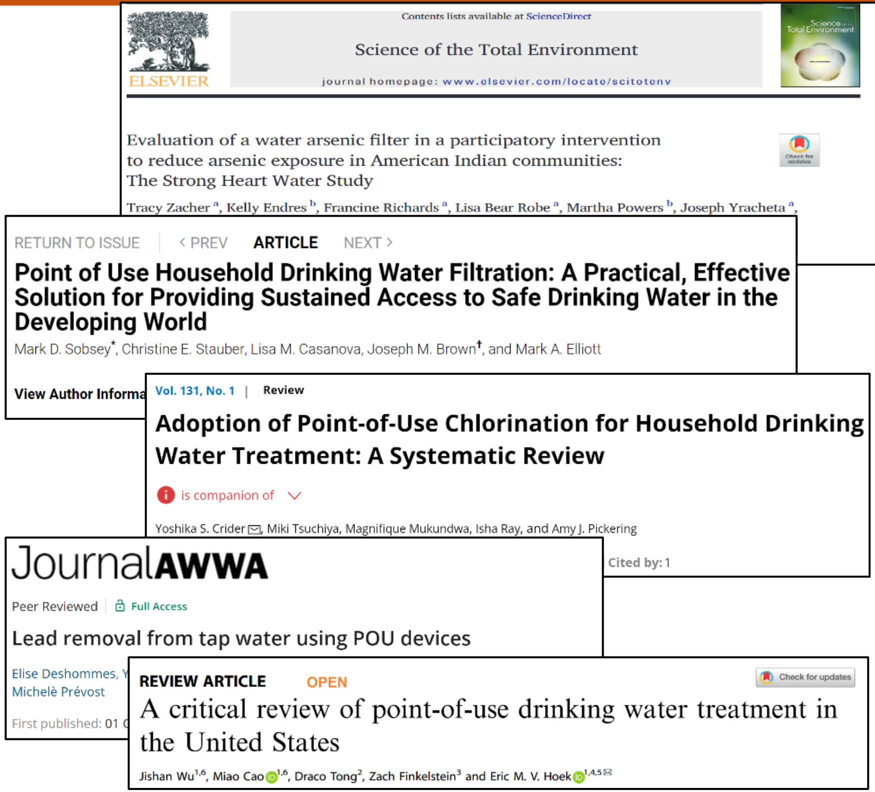
Previous studies have found elevated levels of total coliform, *E. coli*, Pb, Cu, Fe, Mn, and As, among other health- and aesthetic-based contaminants, in private wells.
(Shiber, 2005; Pieper et al., 2015; Flanagan et al., 2016; Law et al., 2017; Mulhern & Gibson, 2020; Patton et al., 2020; Cohen et al., 2022)

Introduction: Roadside Spring Use

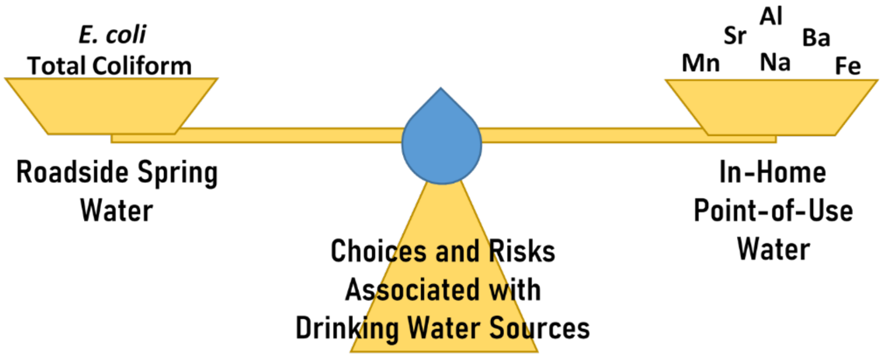
- Used for **drinking/household water**
- **Not regulated** by SDWA
- **No treatment or disinfection**
- **Often perceived to be better quality than in-home tap water**
  (Patton et al., 2020; Krometis et al., 2019)
- Appalachian springs have tested positive for **total coliform** and ***E. coli***
  (Patton et al., 2023; Sinton et al., 2021; Patton et al., 2020; Krometis et al., 2019; Swistock et al., 2015)
- Collection is a **time** and **money** commitment
- **Personal and cultural significance**

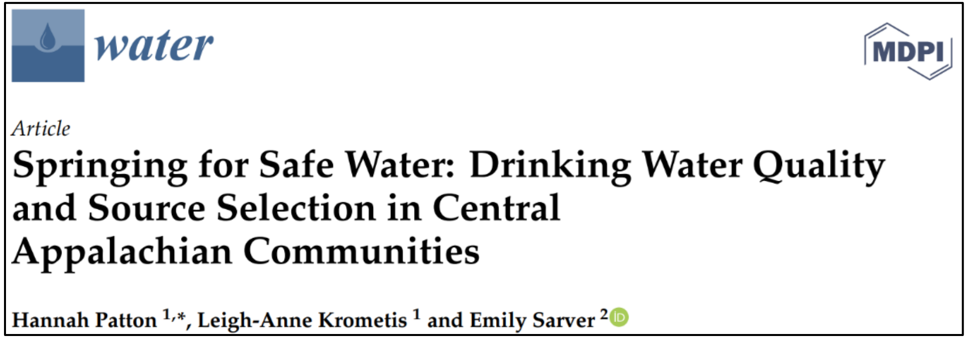
Introduction: Point-of-Use Drinking Water Treatment





Overarching Research Goals:




water
MDPI

Article

Springing for Safe Water: Drinking Water Quality and Source Selection in Central Appalachian Communities

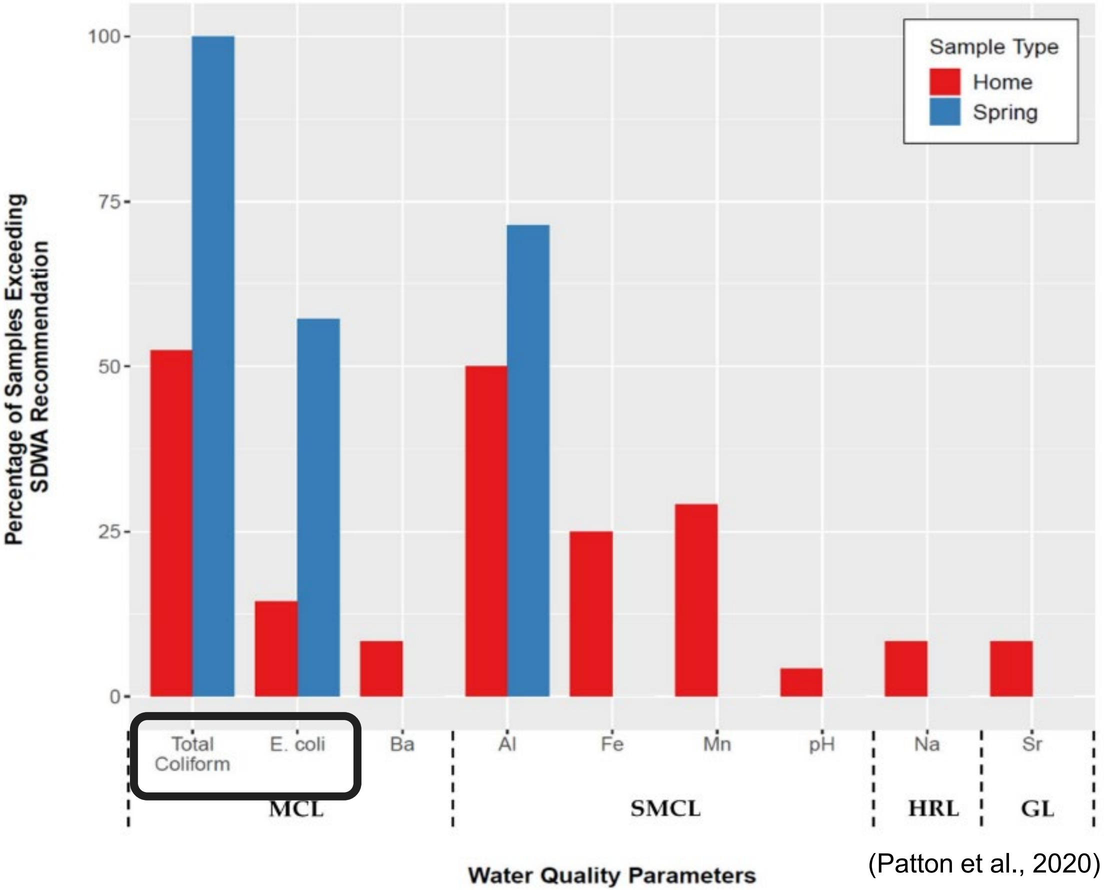
Hannah Patton [1,*], Leigh-Anne Krometis [1] and Emily Sarver [2]

1) **Develop and implement a simple, low-cost protocol using household bleach to inactivate total coliform and *E. coli* in untreated roadside spring water**
2) **Determine the effectiveness of commercially available end-of-faucet POU filters in improving microbial and chemical water quality in homes dependent on private wells**

Developing a simple strategy for roadside spring water disinfection in Central Appalachia

Patton, H., Krometis, L-A.,Faulkner, B., Cohen, A., Ling, E., Sarver, E. (2023). Developing a Simple Strategy for Roadside Spring Water Disinfection in Central Appalachia. *Journal of Contemporary Water Research & Education*. 178. 1-16. 10.1111/j.1936-704X.2023.3388.x.

Roadside Spring Water Quality



(Patton et al., 2020)

Research Goals & Criteria

Research Goals:

1) Develop a **simple, low-cost** protocol using **household bleach** to **inactivate** total coliform and *E. coli* in untreated roadside spring water

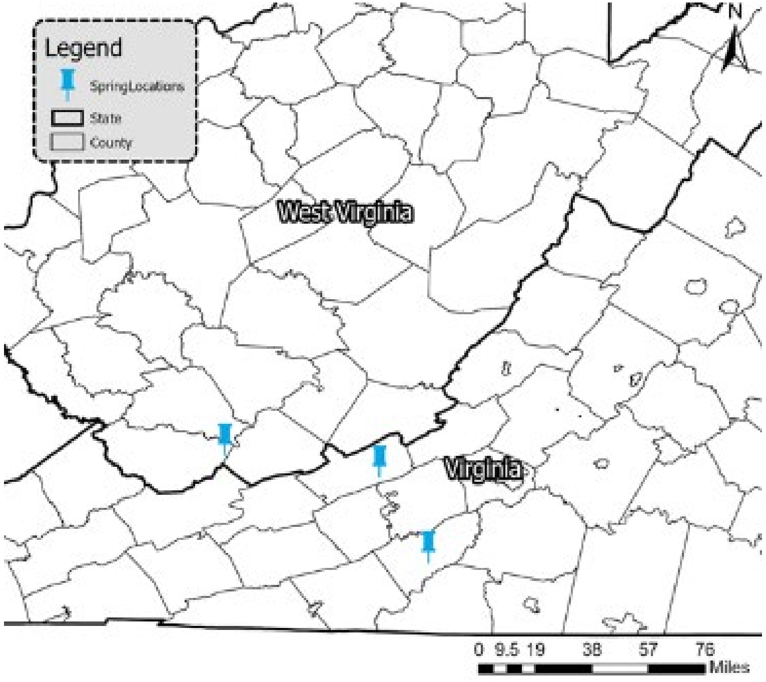
2) Provide **educational materials** at local roadside springs to inform users of this simple treatment strategy

3) **Assess** spring user **perceptions** of the educational materials via a **short survey**

Criteria:

- **100% inactivation** of total coliform and *E. coli* bacteria in roadside spring water
- **Free Cl residual** between 0.5 mg/L and 2.0 mg/L 1-hour post-disinfection, and at least 0.2 mg/L 1-day post-disinfection (as recommended by CDC)
- Attempt to use bleach levels recommended by **WHO** and **CDC** for disinfection of drinking water
- Utilize **realistic** spring water collection and storage conditions

Study Area



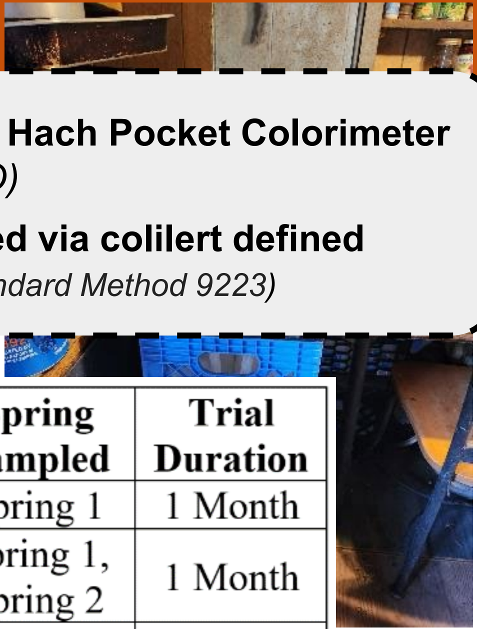
Floyd County, VA

Giles County, VA

McDowell County, WV

Study Design

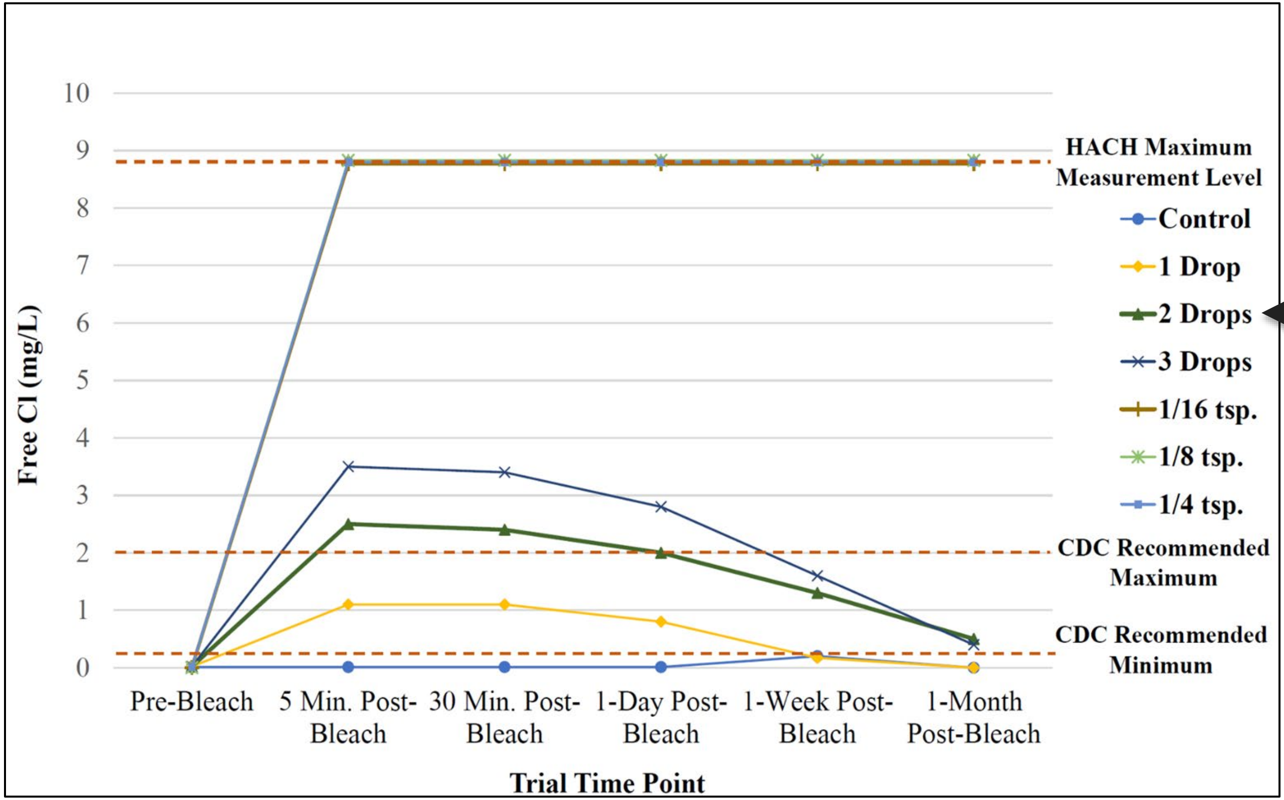
- **Free Cl/Total Cl analyzed via Hach Pocket Colorimeter** *(Hach Company; Loveland, CO)*
- **Total coliform/*E. coli* analyzed via colilert defined substrate method** *(IDEXX; Standard Method 9223)*



Trial Number	Bleach Brand	Bleach Treatment Volume (per 1 gallon of water)	Number of Samples (n)	Spring Sampled	Trial Duration
1	NB	0 tsp, 1/4 tsp	8	Spring 1	1 Month
2	NB	0 tsp, 1/8 tsp, 1/16 tsp	12	Spring 1, Spring 2	1 Month
3	NB	0 drops, 3 drops, 2 drops, 1 drop	4	Spring 1	1 Month
4	NB, SB	0 drops, 2 drops	6	Spring 1	1 Month

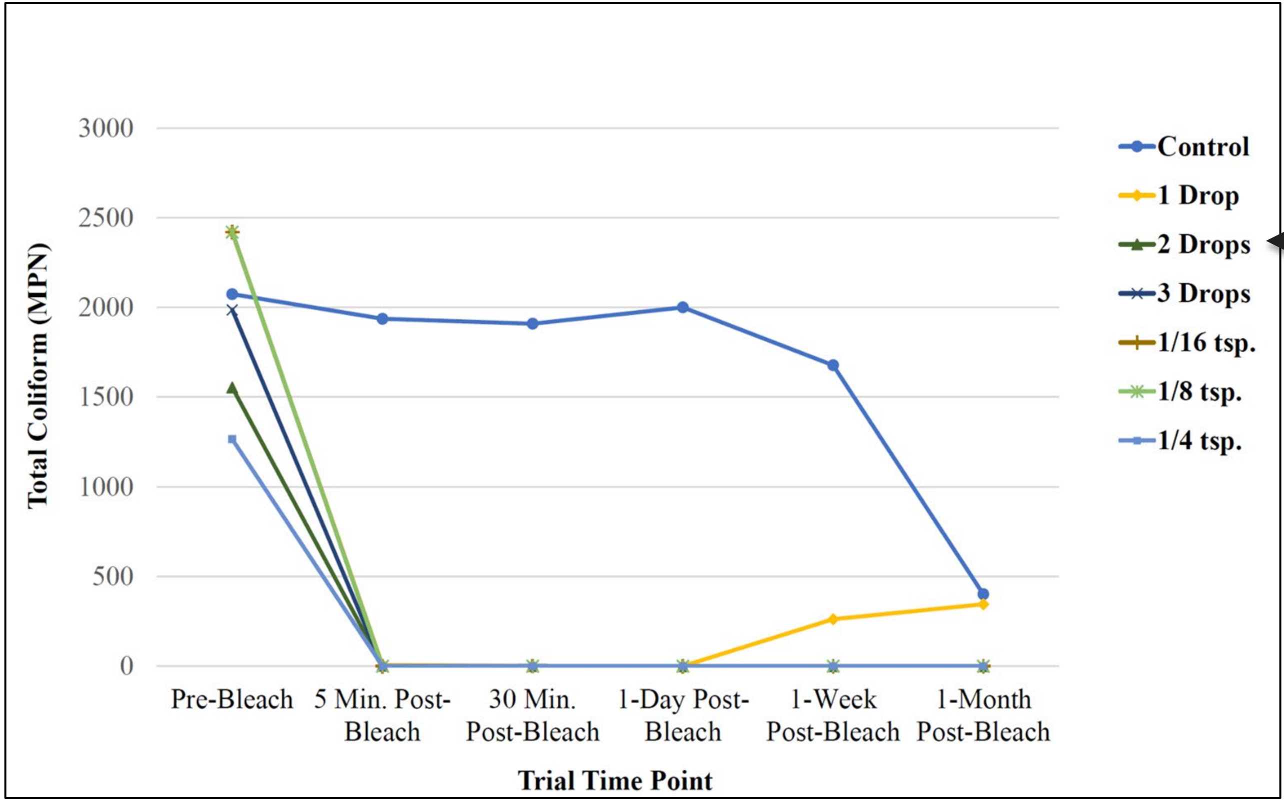
(NB = Name-Brand, SB = Store-Brand)

Bleach Protocol Free Cl Results



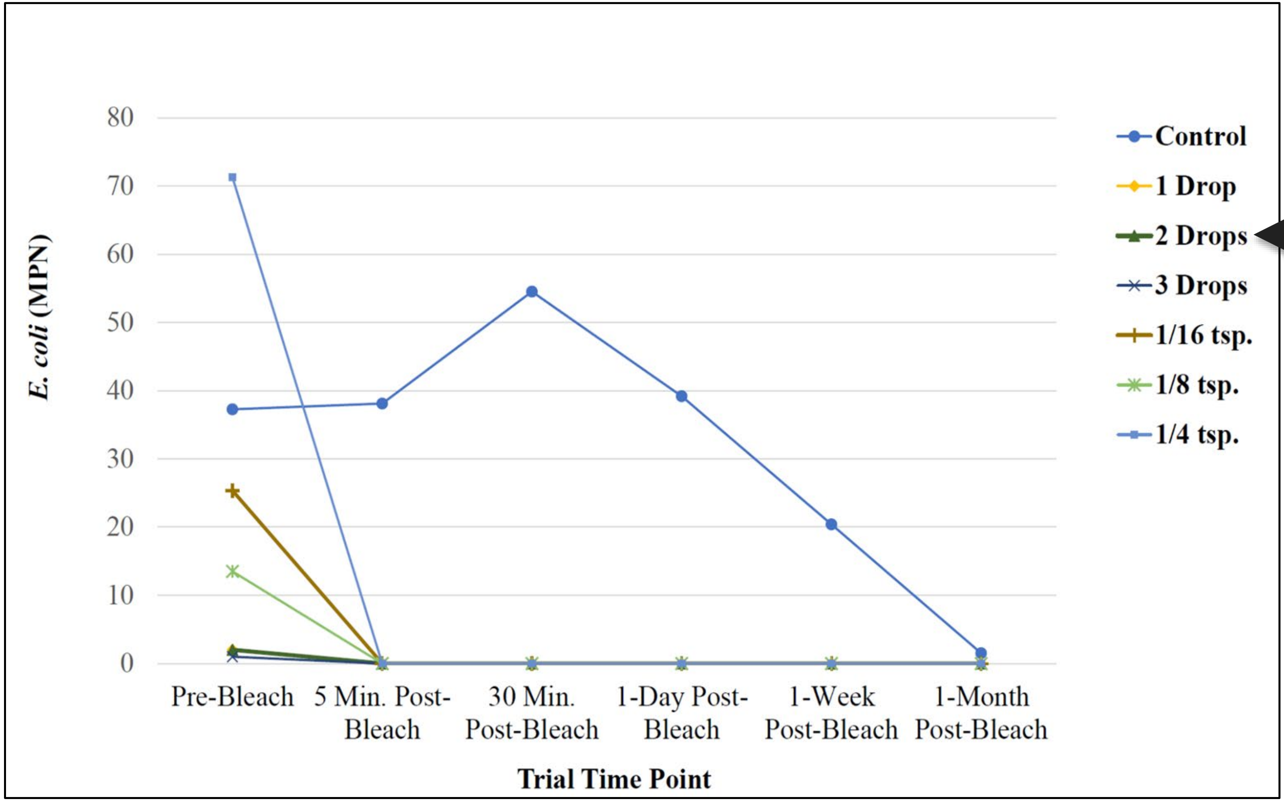
2 drops of bleach in 1 gallon of spring water

Bleach Protocol Total Coliform Results



2 drops of bleach in 1 gallon of spring water

Bleach Protocol *E. coli* Results



2 drops of bleach in 1 gallon of spring water

Bleach Protocol Infographic Development

Is this spring water safe to drink?

This spring has tested positive for *E. coli* bacteria.
Spring data available here: https://tinyurl.com/WVVAspring

You can remove bacteria like *E. coli* from spring water by adding a **small amount** of bleach.

E. coli bacteria in drinking water is a health risk and can make you sick.

Questions? Please contact:
hpatton@vt.edu or 540-231-4372

How to Disinfect Spring Water with Bleach

Adding a **small amount** of household bleach to spring water is safe and can help kill harmful bacteria.

1. Fill a **clean one-gallon** jug with spring water.
2. Fill eye-dropper with regular household bleach. Do **NOT** use scented or splash-less bleach.
3. Use eye-dropper to put **2 drops** of bleach in the spring water jug. Cap and turn the jug upside down. Wait **30 minutes** before using.
4. Store spring water in a refrigerator or in a cool spot in your home. Do not drink water after 1 week.

30 min

Bleach Protocol Infographic Survey

We Want to Hear from You!

Please answer the following questions:

Answer online at:
https://tinyurl.com/
RoadsideSpringSurvey

1. What do you use spring water for? Please check all that apply.

☐ Drinking ☐ Cooking ☐ Cleaning ☐ Brushing teeth ☐ Farming/Gardening
☐ Livestock/Pets ☐ Other: ______________________________

2. Did you know that spring water can have harmful bacteria in it?

☐ Yes ☐ No ☐ Other: ______________________________

3. Do you already disinfect your spring water? If yes, how?

☐ Yes, boiling ☐ Yes, chlorine ☐ Yes, other: _______________ ☐ No

4. Will you use the instructions for bleach disinfecting your spring water?

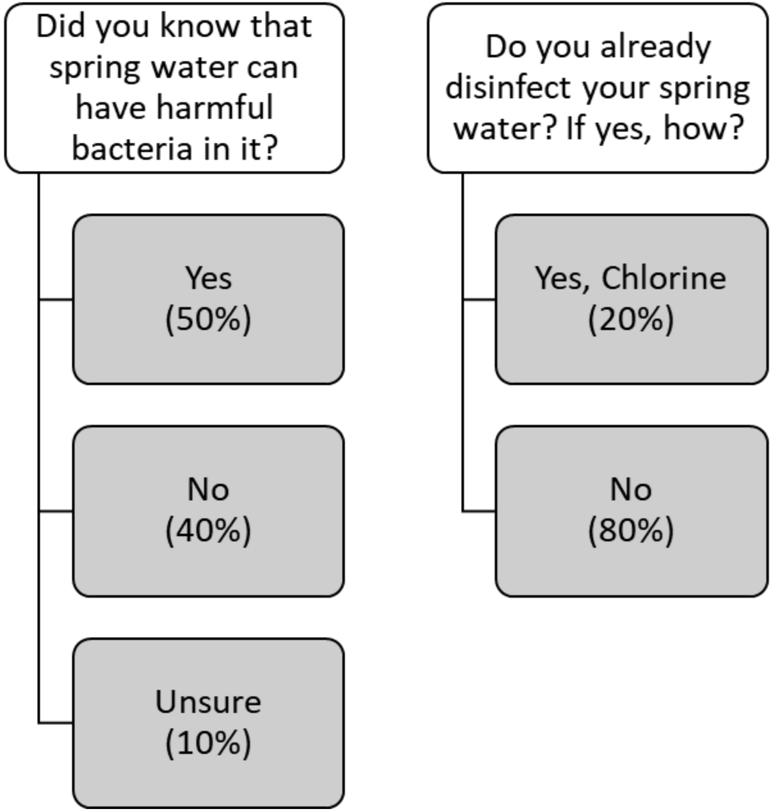
☐ Yes ☐ No ☐ Maybe ☐ Other: ______________________________

5. How helpful did you find this information?

☐ Very helpful ☐ A little helpful ☐ Not helpful ☐ Other_______________

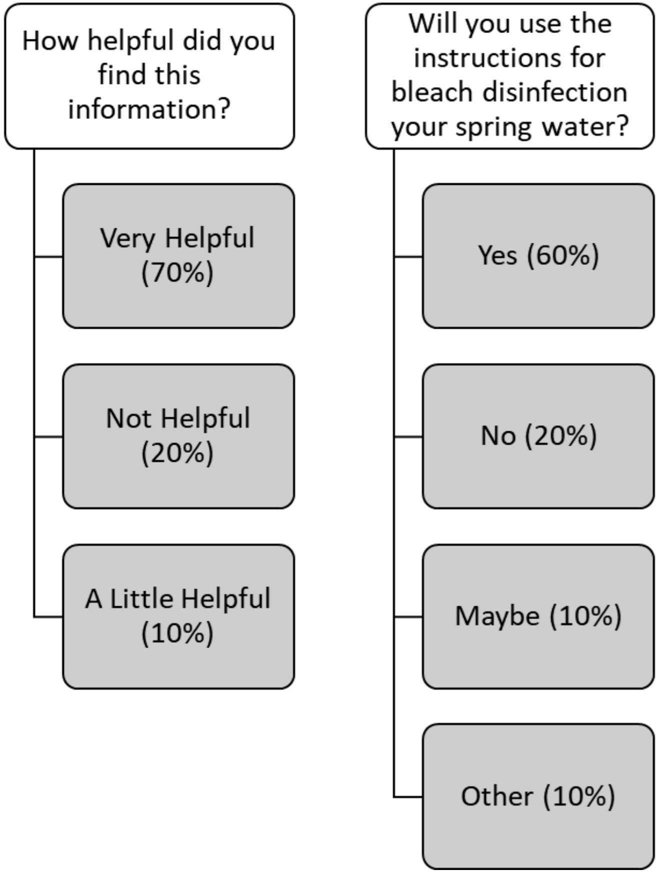
Please write any other comments or suggestions that you have on the back.

Bleach Protocol Survey Results



n = 10

Bleach Protocol Survey Results



n = 10

Limitations

- Tested only 7.4-7.5% sodium hypochlorite bleach
- Tested on recently purchased bleach
- Bleach is not effective in removing chlorine-resistant waterborne pathogens (e.g. *Cryptosporidium*)
- Water turbidity of 0.0 - 0.13 NTU
- Convenience based surveying

Conclusions

Pros	Cons

Pros

- **2 drops** of commercially available **regular household bleach** provided sufficient **disinfection** and **free Cl residual** in **1 gallon** of roadside spring water for up to **1 month.**
- Efforts to provide spring users with information involving spring water quality and disinfection were considered **helpful**

Cons

- Bleach is not effective in removing **chlorine-resistant** waterborne pathogens (e.g. *Cryptosporidium*)
- Bleach disinfection is not as effective in **highly turbid water**
- Only **60%** of respondents reported that they intended to use the disinfection protocol

Additional research on **risks** associated with roadside spring water use, and efforts to **expand and improve** water infrastructure, are needed to better understand and address health risks in **roadside spring-reliant communities**.

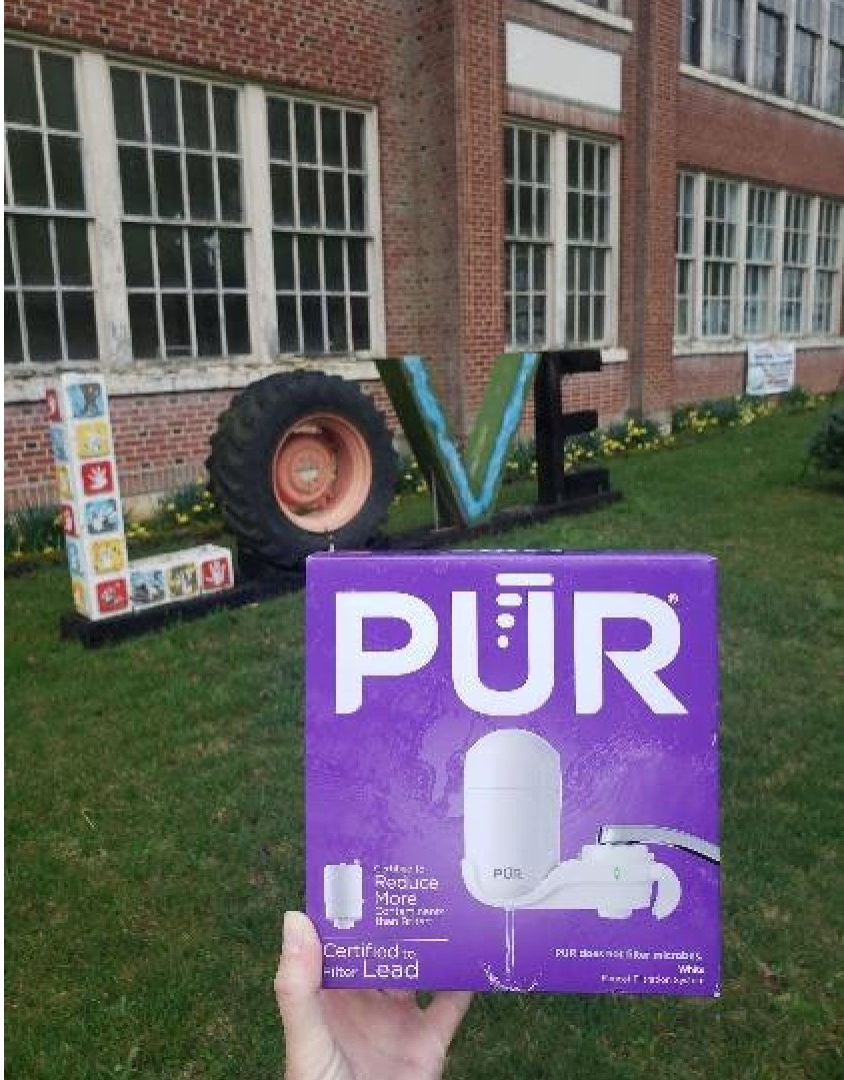
Virginia Household Water Quality Program

Virginia Cooperative Extension
Virginia Tech • Virginia State University

Virginia Environmental Endowment

Faucet-mounted point-of-use drinking water treatment to reduce exposure to aesthetic and health-based contaminants in homes served by private wells

Patton, H.*, Krometis, L-A., Ling, E., Cohen, A., Sarver, E. (2023). Faucet-mounted point-of-use drinking water treatment to reduce exposure to aesthetic and health-based contaminants in homes served by private wells. *Science of the Total Environment.* 906(2): 167252. 10.1016/j.scitotenv.2023.167252



POU Water Filter Treatment Applications

Success of POU faucet filters in removing Pb (and other metals) from homes on municipal water is well-documented…

JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH, PART A
2019, VOL. 54, NO. 5, 484–493
https://doi.org/10.1080/10934529.2019.1611141

Taylor & F
Taylor & Francis G

Check

POU water filters effectively reduce lead in drinking water: a demonstration field study in flint, Michigan

Valerie Bosscher[a], Darren A. Lytle[b], Michael R. Schock[b], Andrea Porter[a], and Miguel Del Toral[a]

[a]Ground Water & Drinking Water Branch, EPA Region 5, Chicago, IL, USA; [b]NRMRL, WSD, DWTDB, EPA Office of Research and Developm
Cincinnati, OH, USA

EPA United States Environmental Protection Agency

News Releases from Region 05

Filtered water deemed safe for everyone in the Flint community

Interagency testing shows filters are effective in removing high levels of lead in Flint water

06/23/2016

ENVIRONMENTAL Science & Technology

pubs.acs.org/est | Article

Lead Particle Size Fractionation and Identification in Newark, New Jersey's Drinking Water

Darren A. Lytle,* Michael R. Schock, Casey Formal, Christina Bennett-Stamper, Stephen Harmon, Mallikarjuna N. Nadagouda, Daniel Williams, Michael K. DeSantis, Jennifer Tully, and Maily Pham

Cite This: *Environ. Sci. Technol.* 2020, 54, 13672–13679 | Read Online

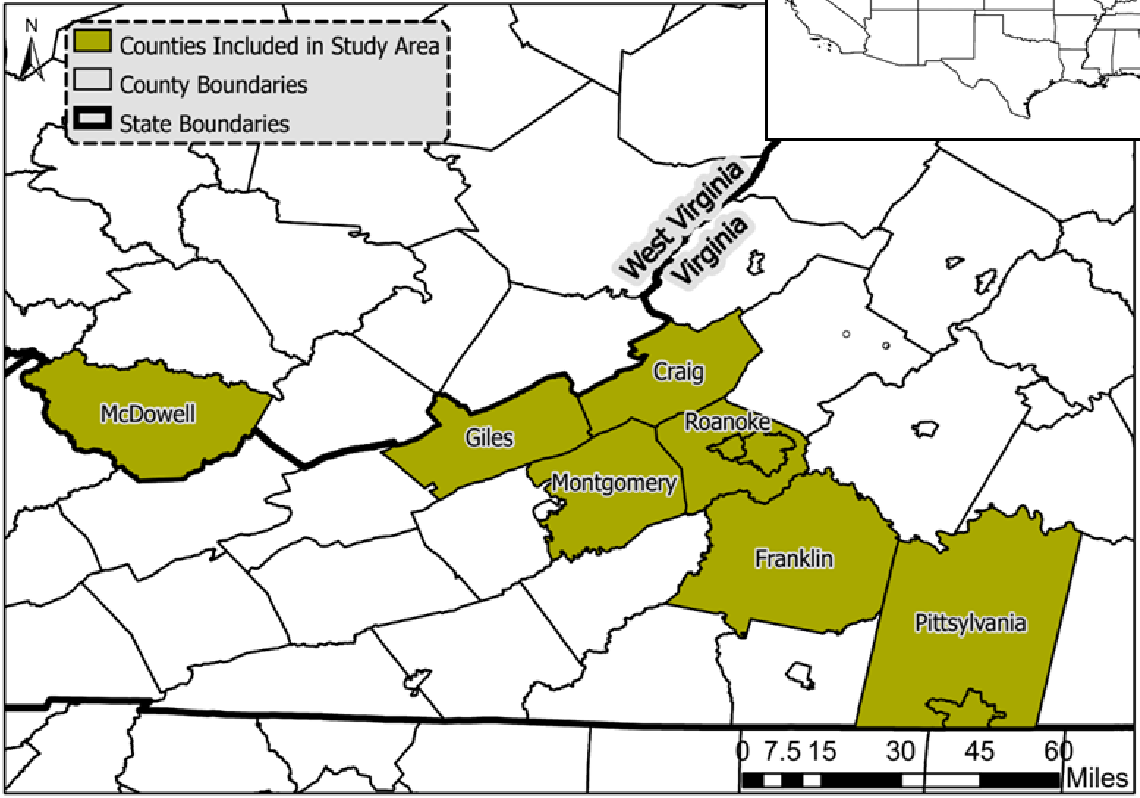
What about in private wells where water chemistry is often drastically different?

Research Objectives

1. Determine the effectiveness of commercially available end-of-faucet POU filters in improving microbial and chemical water quality in homes dependent on private wells
2. Document household ease-of-use and satisfaction with this intervention

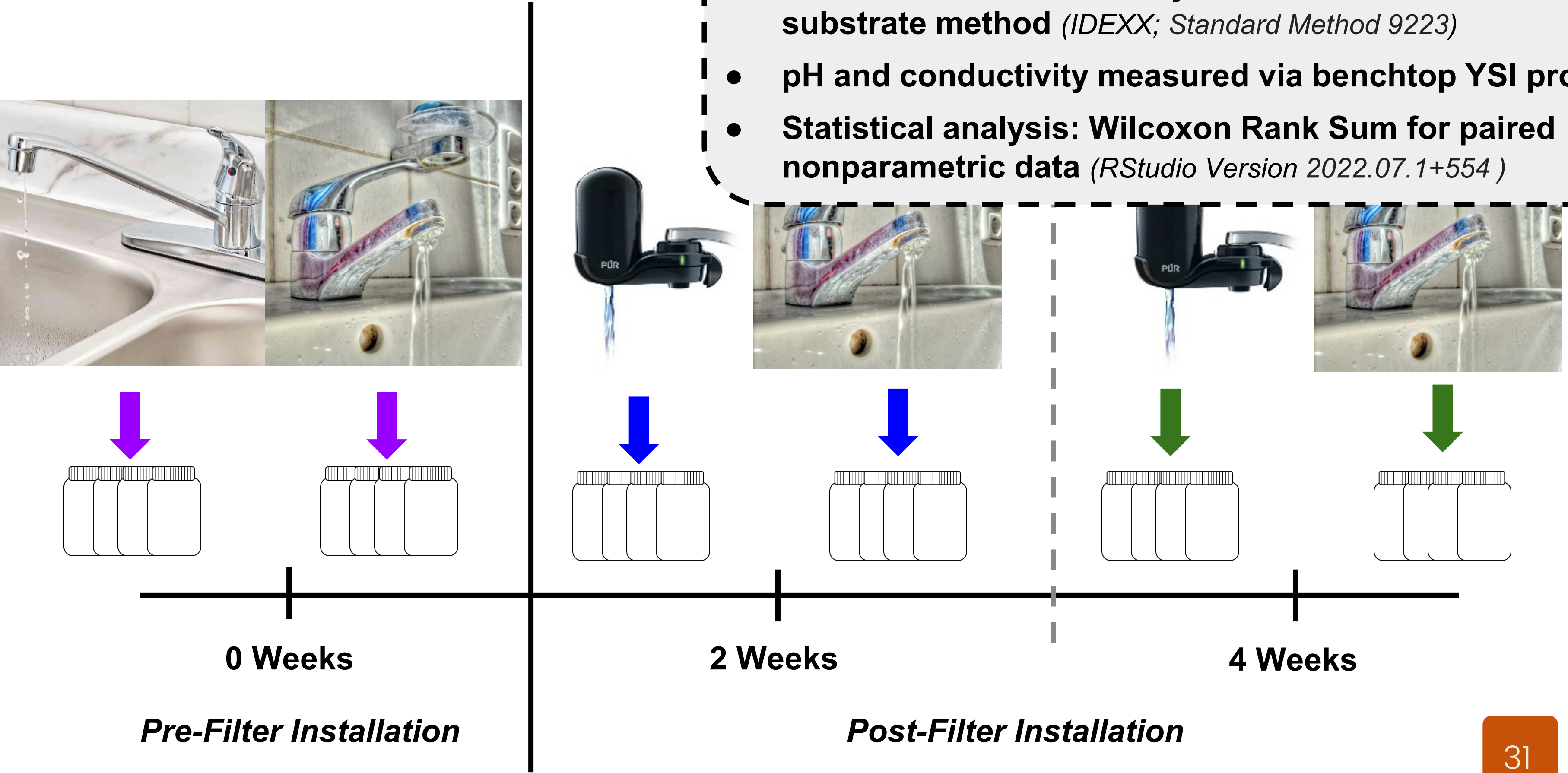
Participant Recruitment and Study Area

n = 21



Study Design

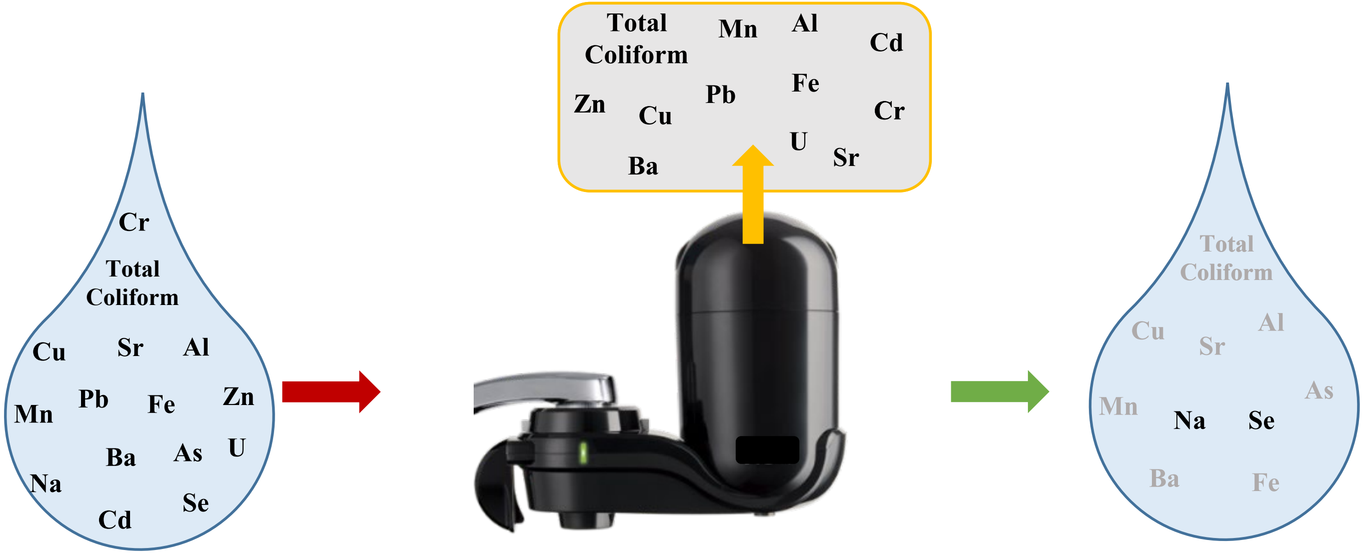
- **First- and second-draw samples analyzed for metals using ICP-MS** *(Standard Methods 3030D and 3125B)*
- **Total coliform/*E. coli* analyzed via colilert defined substrate method** *(IDEXX; Standard Method 9223)*
- **pH and conductivity measured via benchtop YSI probe**
- **Statistical analysis: Wilcoxon Rank Sum for paired nonparametric data** *(RStudio Version 2022.07.1+554)*



Characterizing Unfiltered Tap Water

- **Pb** levels exceeded SDWA MCL (15 ppb) in **33%** of homes with a maximum detected concentration of **178.5 ppb**
- **Fe** levels exceeded SDWA SMCL guidelines (300 ppb) in **33%** of homes with a maximum detected concentration of **9,475 ppb**
- **Total coliform** was the most commonly detected contaminant with over **60%** of homes testing positive, exceeding SDWA MCL (0 MPN)
- Levels of **Ba, Cu, Al, Mn, Zn, Na,** and **Sr** exceeded SDWA regulations/recommendations in **at least one sample** from both unfiltered primary and secondary taps
- **Levels of total coliform and all metals of interest were not statistically significantly different between unfiltered primary and unfiltered secondary tap water samples (Wilcoxon Rank Sum Test; $p > 0.05$)**

Characterizing Filtered Tap Water



Participant Perceptions

Pre-Filter Installation

- Contaminants detected at **60%** of taps
- Tap water used for multiple household uses including **drinking, cooking, cleaning, and brushing teeth**
- **62%** of participants **trust** home water
- **67%** report **aesthetic issues** with tap water

Post-Filter Installation

- **76%** of participants used filter **2-10 times/day**
- **48%** of participants reported that they **liked using this filter**
- **67%** of participants **trust** filtered tap water
- **19%** report **aesthetic issues** with water
- Issues with **flow rate** and **bulky design**

Conclusions

Pros

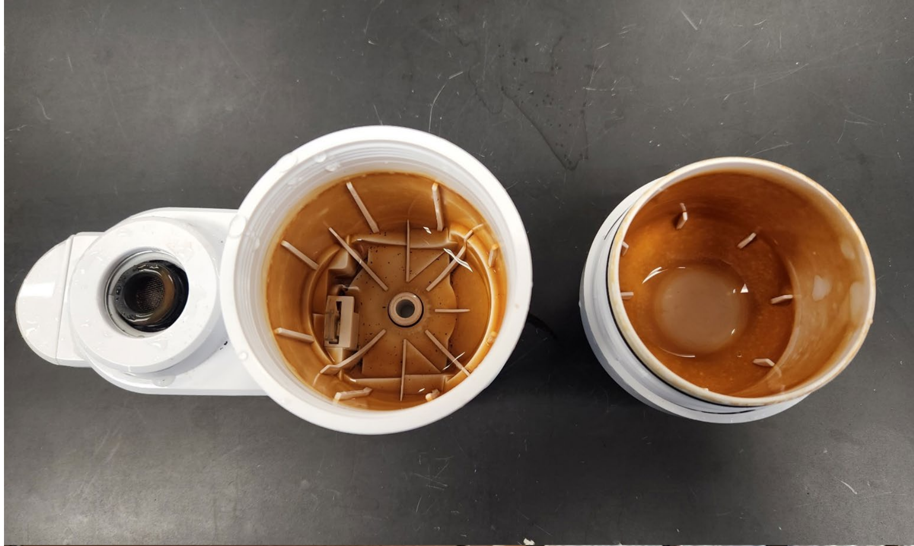
- Drinking water filtered by faucet-mounted POU filters had **statistically significantly lower** levels of **Ba, Cd, Cr, Total Coliform, U, Cu, Pb, Al, Fe, Mn, Zn, and Sr**
- Filters did appear to **lower levels of Total Coliform** in drinking water
- Filter users reported **improved aesthetics** of filtered drinking water

Cons

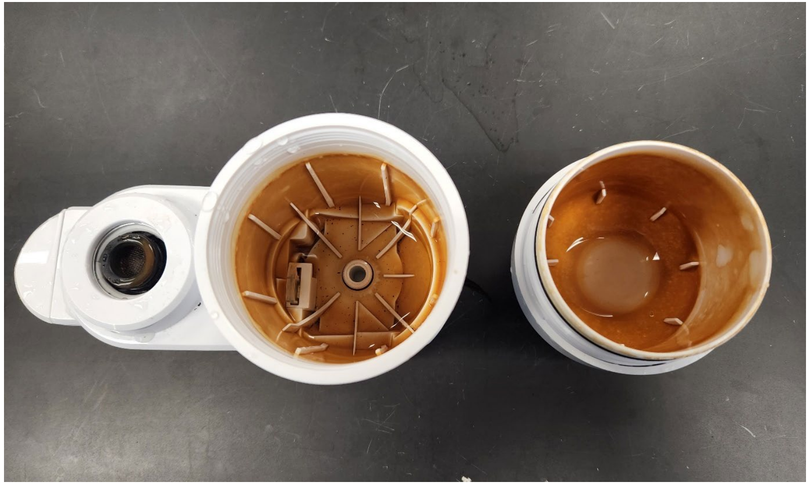
- **High levels** of contaminants in **source water** can alter filter effectiveness. Levels of many contaminants **exceeded SDWA recommendations** in filtered water (e.g. Total Coliform, Cu, Ba, Fe, Mn, Na)
- Filters **do not** provide complete protection from **microbial contaminants**
- Filter users reported **issues** with **slow flowrate**, **bulky design**, and **installation**

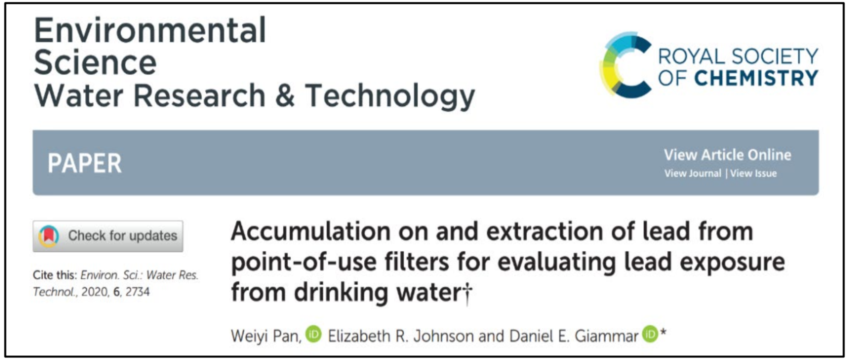
To inform and support **POU faucet filter adoption** in homes, further research must explore **user knowledge and preferences**, **filter flowrate and design**, and the effects of **unfiltered source water quality** on filter performance

Recovery of Pb, Fe, and Cu from POU filters to examine performance



Research Objectives





Environmental Science Water Research & Technology

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Cite this: *Environ. Sci.: Water Res. Technol.*, 2020, **6**, 2734

Accumulation on and extraction of lead from point-of-use filters for evaluating lead exposure from drinking water†

Weiyi Pan, Elizabeth R. Johnson and Daniel E. Giammar *

1) Determine filter removal of metals under low and high concentration conditions in a lab setting

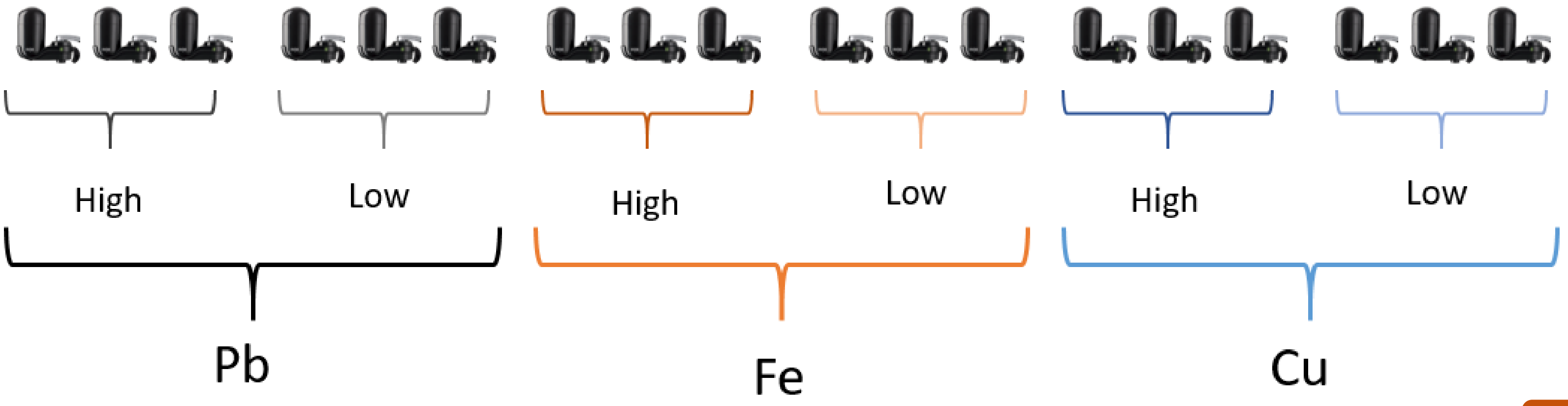
2) Assess the effectiveness of the acid flow-through method as a means of recovering metals from used faucet-mounted POU filters.

Filter Dosing Method

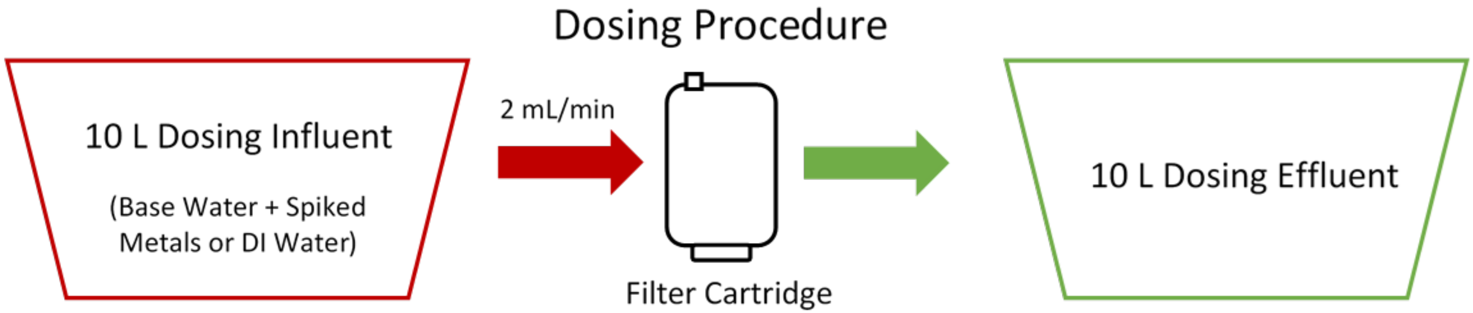
Dosing Influent (10L per filter):

- ANSI/NSF 53 Base Water Recipe: $MgSO_4$, $CaCl_2$, and $NaHCO_3$
- $PbNO_3$ or $CuCl_2$ or $FeSO_4$

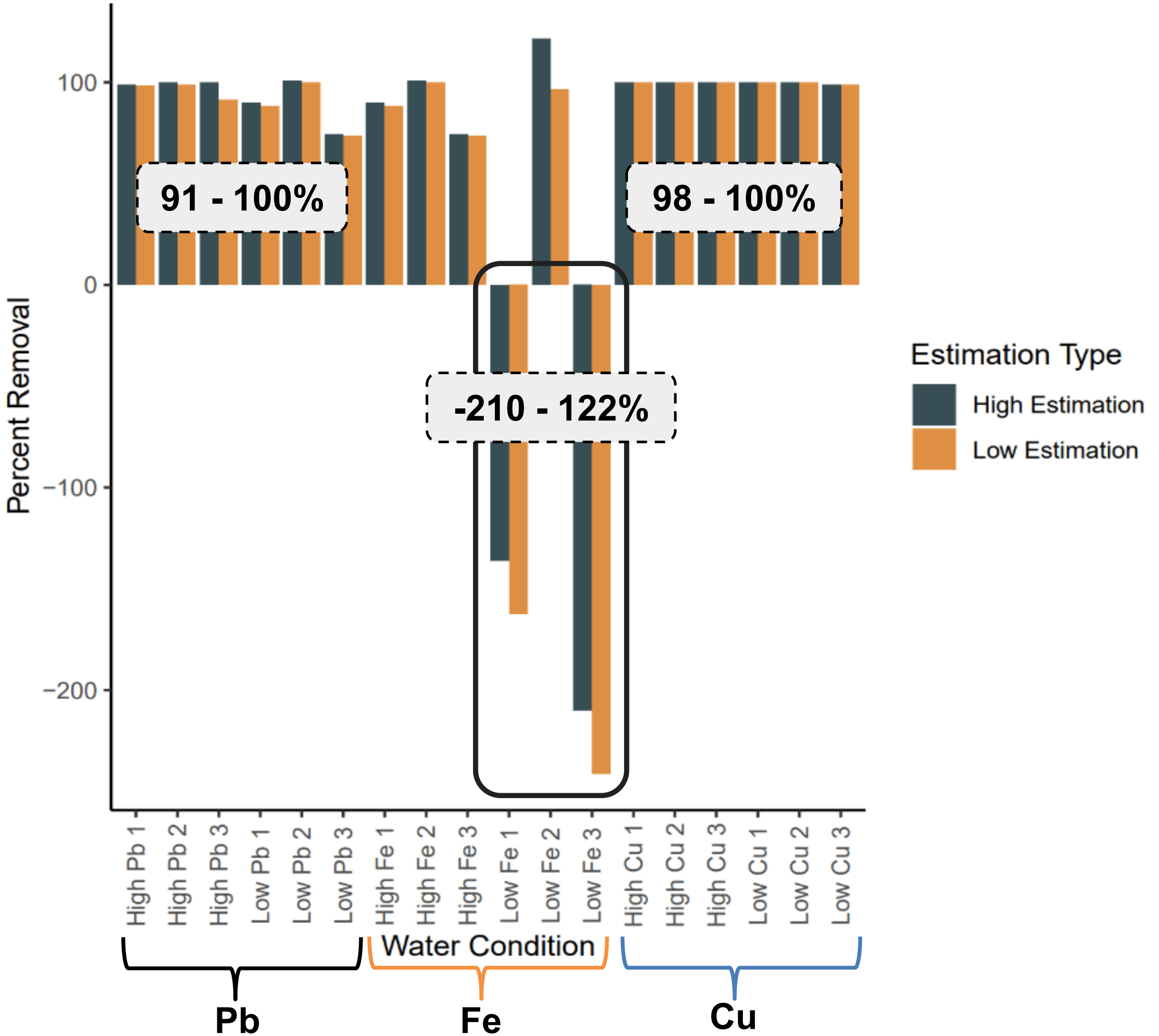
Water Type	Desired Concentration (ppb)	Actual Concentration (ppb)	pH	% Particulate
High Pb	400	319.3-363.2	7.04-7.12	2.6-10.9
Low Pb	5	4.0-4.7	7.00-7.08	32.3-36.7
High Fe	10,000	10,678.9-10,841.9	6.48-6.59	97.3-98.8
Low Fe	300	358.9-370.2	6.47-6.55	68.5-96.1
High Cu	4,000	3,823.7-3,948.4	6.14-6.29	4.9-9.0
Low Cu	1,300	1,305.6-1,325.7	6.26-6.34	3.0-12.8
DI Water Control	NA	NA	6.40-6.50	NA



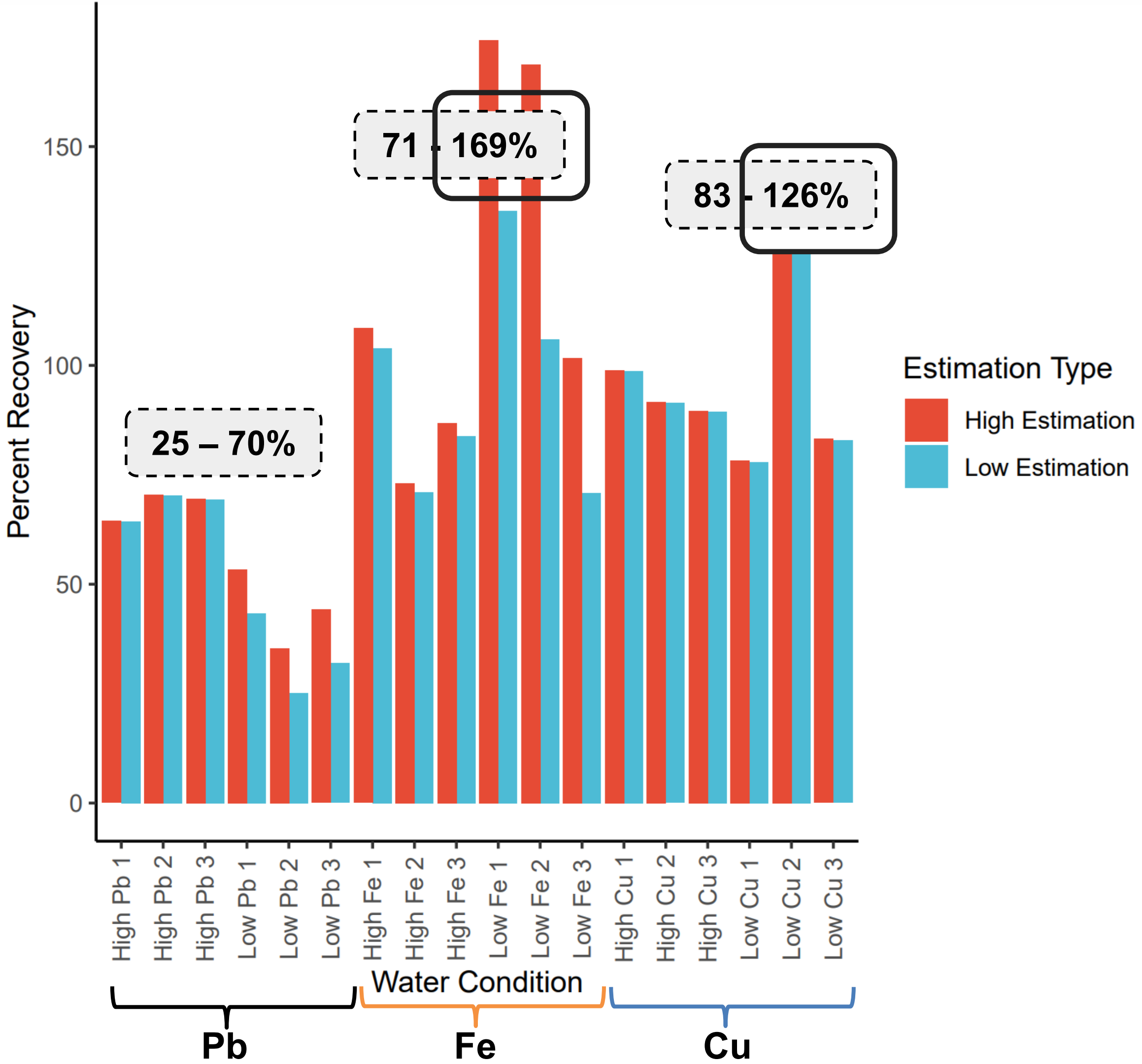
Filter Dosing + Acid Flow-Through Procedures



% Removal Results



% Recovery Results

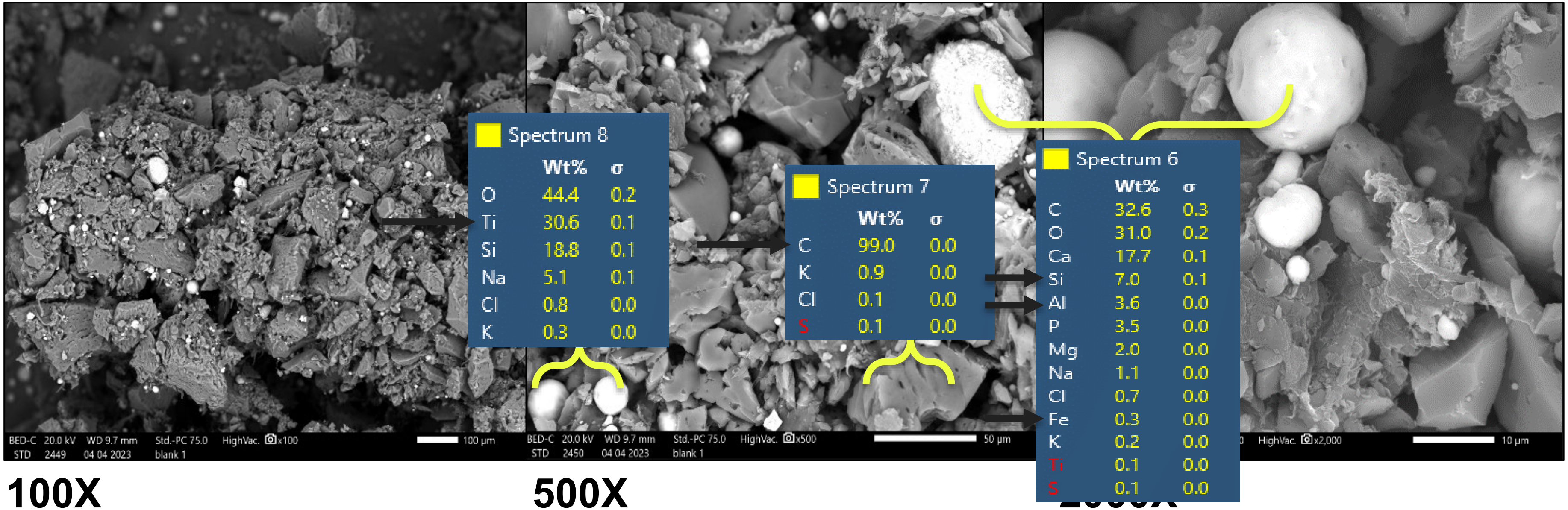


Metals Leaching – Handheld XRF Analysis

Sample Type	Light Energy (wt%)	Ti (wt%)	Pb (wt%)	Fe (wt%)	Cu (wt%)

Metals Leaching – SEM EDS Analysis

Blank Filter Cartridge – BSD Images



Spectrum 8

	Wt%	σ
O	44.4	0.2
Ti	30.6	0.1
Si	18.8	0.1
Na	5.1	0.1
Cl	0.8	0.0
K	0.3	0.0

Spectrum 7

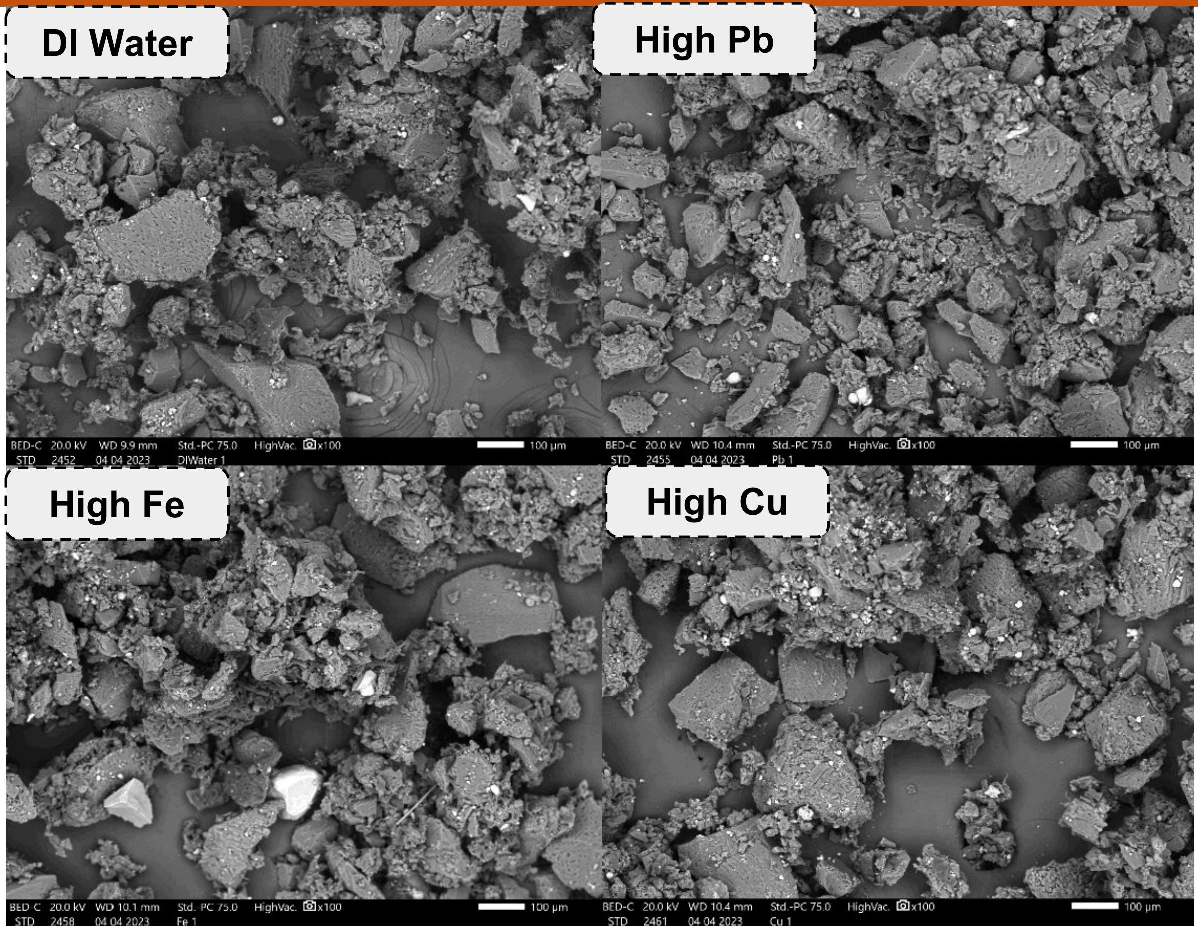
	Wt%	σ
C	99.0	0.0
K	0.9	0.0
Cl	0.1	0.0
S	0.1	0.0

Spectrum 6

	Wt%	σ
C	32.6	0.3
O	31.0	0.2
Ca	17.7	0.1
Si	7.0	0.1
Al	3.6	0.0
P	3.5	0.0
Mg	2.0	0.0
Na	1.1	0.0
Cl	0.7	0.0
Fe	0.3	0.0
K	0.2	0.0
Ti	0.1	0.0
S	0.1	0.0

100X **500X**

Metals Leaching – SEM EDS Analysis



Acid Flow-Through Filters

- All samples were **primarily C (>80%)**
- **Si, Ti, Al, and Ca** quantified in all samples (white spherical particles)
- **No Pb or Cu** detected in any samples
- **Fe** detected in all of the samples
- **Different species** of Fe in High Fe sample

Conclusions

Pros

- Over **90%** of **dosed Pb and Cu** was removed via POU faucet filters
- Over **83%** of **dosed Cu** was recovered using the **acid flow-through procedure**

Cons

- **25-70%** of **dosed Pb** was recovered using the **acid flow-through procedure**
- **Fe leaching** from filter media results in inconsistent and variable Fe **recovery and removal estimates**
- Variable filter removal performance under Fe concentrations > 300 ppb
- Cu, Fe, and several other metals (e.g., Ti, Si, Al) were observed to leach from filters during the acid flow-through procedure

Variable recovery estimates and metals leaching suggest that alternate methods for assessing uptake of metals to POU filters should be explored.

Overall Conclusions: Bringing It All Together

Pros

- Bleach disinfection of roadside spring water successfully **inactivates total coliform** and ***E. coli*** in water and provides sufficient free Cl residual
- **Faucet-mounted POU filters reduce levels of many contaminants of interest (total coliform, Pb, Fe, etc.) in private well water**
- **The acid flow-through procedure for metals extraction from used faucet filters provided over 83% Cu recovery**

Cons

- Lack of consumer **knowledge, understanding, and trust** in treatment strategies results in limited adoption
- **Extreme source water conditions and low filter flowrates limit filter performance and adoption**
- **The acid flow-through procedure had variable performance when extracting Pb and Fe from used filters and metals leached during the process.**

In order to improve **water quality** and POU water treatment **adoption** in homes using private wells or roadside springs as drinking water sources, additional research efforts must address these **limitations** and focus on **convenient, inexpensive, and effective POU water treatment.**

Future Efforts and Food for Thought

- POU water treatment is **not** one-size fits all
- In order to effectively treat household drinking water, a **better understanding of source water chemistry** is necessary
- In order to effectively reduce exposure to harmful drinking water contaminants, a **better understanding of health risks associated with different drinking water sources** is necessary
- POU water treatment **can't** be considered a **sustainable, long-term drinking water quality solution** for people in rural areas struggling with poor drinking water quality
- **Resources, research efforts, and energy** needs to be directed towards implementing and improving the **large-scale, widespread provision of safe drinking water** in rural communities.

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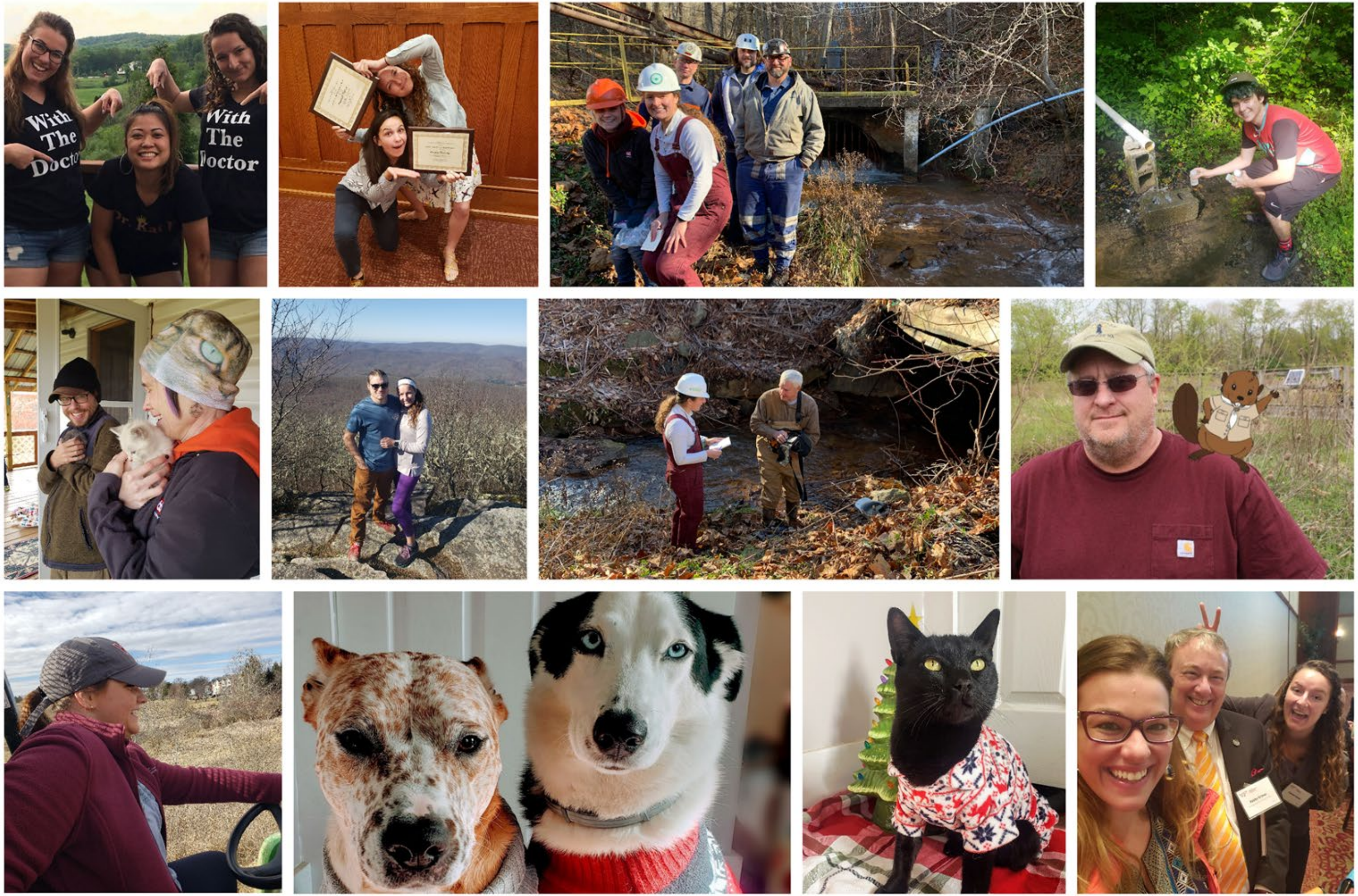
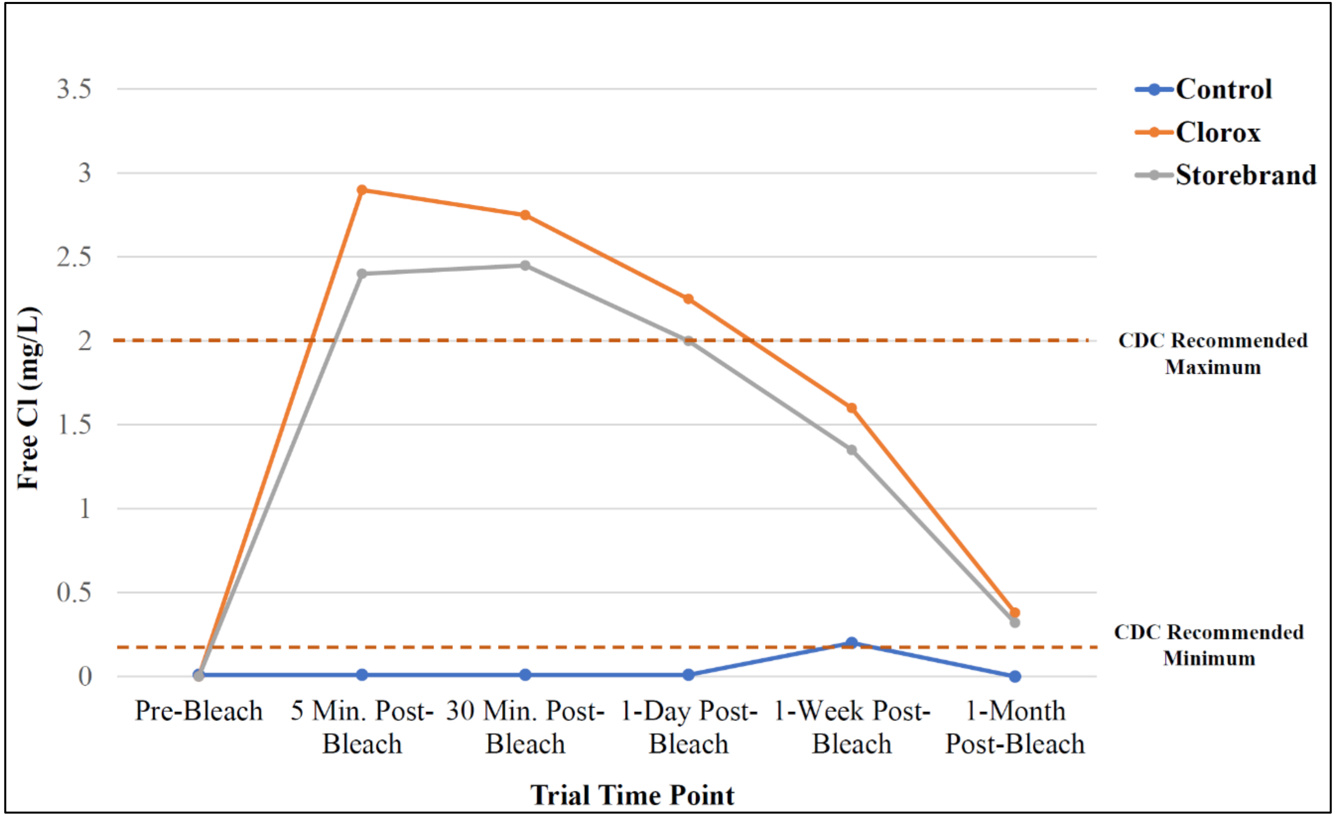


Thank You!

Chapter 1 Supplementary



Chapter 1 Supplementary

Table 4.4: Dosing influent, dosing effluent, acid-rinse, and acid flow-through recovery loading data collected during control water condition testing. Table features metals on interest (Pb, Fe, Cu) as well as other metals that were observed to be leaching out from filter media during dosing and/or acid flow-through recovery (Ti, Al, Si).

		Dosing Influent Loading (ppb)						Dosing Effluent Loading (ppb)						Acid Flow Through Effluent Loading (ppb)					
Water Type	Filter #	Pb	Fe	Cu	Ti	Al	Si	Pb	Fe	Cu	Ti	Al	Si	Pb	Fe	Cu	Ti	Al	Si
DI Water	19	0.9	-91.8	5.0	4.2	21.0	7,847.4	0.00	-51.0	4.33	92.67	273.67	2.3e5	1.33	3.2e4	2,006.7	1.1e6	3.8e4	3.3e5
DI Water	20	0.2	-110.1	2.0	3.5	21.3	8,035.2	0.00	-184.0	3.00	67.6	35.6	2.0e5	5.48	3.4e4	2,120.0	1.1e6	3.8e4	3.1e5
DI Water	21	2.9	-95.5	8.0	1.1	24.5	8,068.1	2.00	905.0	4.00	83.3	254.6	2.0e5	2.13	3.4e4	2,080.0	1.1e6	3.8e4	2.9e5