

Characterizing Private Well Water User Perceptions of Risk, Testing, and Treatment to Support Workshop and Resource Development

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Abstract Approximately 14% of the U.S. population relies on private wells for drinking water. Little is known about well stewardship, well water contaminants and their health impacts, ideal water testing frequency, and preferred water treatment. Our mixed-methods study focused on identifying well stewardship practices and beliefs in Colorado. We contacted septic permit holders and enrolled them in this study if they met eligibility criteria. Although annual testing is recommended, only 8.2% of study participants had tested their water in the past year, and 45.5% of participants reported treating their water. Differences in practices and beliefs were observed based on income and education levels. Identified gaps in knowledge, testing, and treatment suggest that public–private partnerships and increased development of resources, annual reminders, and better access to testing might improve stewardship and the overall health of well users. Well users could benefit from increased access to resources about well stewardship—specifically testing and treating well water—to improve drinking water safety.

Keywords: well stewardship, drinking water, water quality testing, well user perceptions and behaviors

Introduction

In the U.S., approximately 14.1% of the population relies on private wells for drinking water (Murray et al., 2025). In Colorado, that estimate is 7% (Colorado Environmental Public Health Tracking, n.d.). Although the Safe Drinking Water Act charges the U.S. Environmental Protection Agency with setting regulations for water quality to ensure that specified contaminants are not present above the maximum contaminant level (MCL), private wells are not included under the umbrella of regulatory authority for public water systems

(Safety of Public Water Systems, n.d.). Water quality from private wells is not regulated by the Colorado Department of Public Health and Environment nor by any other Colorado agency (Colorado Department of Public Health and Environment, n.d.).

This lack of federal and state regulation shifts primary responsibility for well stewardship—including water quality monitoring, treatment, and well maintenance—to individuals. The Centers for Disease Control and Prevention (CDC, 2024b, 2024c) recommends annual private well testing and

the selection and verification of treatment technologies appropriate for contaminants detected through testing. The cost burden of testing and treatment, however, falls to individuals (Lade, 2024), and many well owners have limited knowledge of options for testing and treating their well water (Malecki et al., 2017). Consequently, many households consume well water that is untested and untreated (Malecki et al., 2017; Swistock et al., 2013).

This lack of sufficient testing is concerning given the growing evidence of the prevalence of well water contamination and the potential for wells to be contaminated by a variety of biological, chemical, physical, and radiological contaminants from human-made and naturally occurring sources (Borchardt et al., 2021; Focazio et al., 2006; Lee & Murphy, 2020; Silver et al., 2023; Stokdyk et al., 2025). In the U.S., 23% of domestic wells have at least one contaminant above the MCL (DeSimone et al., 2009; U.S. Environmental Protection Agency, 2026). In one national estimate, approximately 33% of wells had coliform bacteria and 8% had *E. coli*, indicating the potential for fecal contamination (DeSimone et al., 2009).

Although the U.S. has no federal regulation for private wells, each state can develop its own laws, regulations, and policies. Colorado, like most states, primarily focuses on well construction, registration, and general groundwater monitoring, and most private well programs are administered at the county level (Bowen et al., 2019; Schmitt et al., 2024).

Boulder County, for example, has numerous wells (>10,000 permits have been issued as of August 2026) along with distinct geologic and land use regions, contributing to different water quality concerns throughout the county (Colorado Department of Natural Resources, n.d.; Colorado State University Extension, 2013). Yet little is known about well stewardship in Boulder County, such as testing and treatment.

The objectives of our study in Boulder County were 3-fold:

1. Identify private well stewardship practices, including motivations and barriers for testing, well management, and water treatment.
2. Determine the extent to which knowledge and beliefs about well stewardship, reported water quality concerns, well testing, and treatment patterns are associated with income and education levels, as well as determine the appropriateness of reported water treatment given stated concerns and identified water issues.
3. Develop workshops for well users to address community concerns and create meaningful well water stewardship resources for the population.

Methods

Study Population and Location

Study participants were recruited using mailers sent to septic system permit holders in Boulder County, Colorado. Additionally, community partners who provide services to well water users were sent recruitment emails. Interested individuals were directed to complete the online eligibility survey. Eligibility criteria included that participants must live at least a portion of the year in Boulder County, be >18 years, use a private well, and access and complete an online survey written in English.

Study surveys were available from December 9, 2024, to January 15, 2025. Surveys were collected via Qualtrics and included a series of questions about participant demographics, well usage, knowledge about water testing, testing behavior, treatment modalities, and concerns about water. Additionally, participants were asked if they were interested in water testing. Researchers instructed interested participants on how to collect 1 L of well water and deliver it to Boulder County Public Health. Water testing and analysis are ongoing.

The initial process of workshop development was based on survey results, which allowed us to characterize well users in this population and identify common knowledge gaps to develop targeted resources for the community. The first two workshops occurred in August and September 2025, and two workshops were held in May and June 2026. Pre- and post-workshop surveys allow us to measure the effectiveness of the educational components. Future workshops will be scheduled throughout the county, after allowing time to reflect and making necessary changes to the program prior to the next workshop.

Statistical Methods

Survey data are presented first as descriptive statistics and overall trends in beliefs about water safety and well stewardship, perceptions of risk, water testing behaviors, and treatment prevalence. To further explore the data, we used chi-square tests to determine any statistical differences in survey responses about testing and treatment of well water based on reported household income levels and education level, and to explore the appropriateness of treatment modalities, with statistical significance set at $\chi^2 = .05$.

Bivariate statistics based on income and education level were run after excluding participants who did not respond to those questions; participants who responded by stating they did not want to share income or education information remained in the sample to determine any meaningful differences in those responses. Statistical analyses were primarily performed in R (version 2026.01.0), with some preliminary data cleaning using Microsoft Excel. This study was deemed exempt by the Colorado State University Institutional Review Board (Protocol #6417, determination date November 16, 2024).

Results

A total of 953 people took the eligibility survey, of which 930 met the study criteria. A total of 802 unique users completed the study survey, all of whom completed the consent questions and responded to at least some of the remaining survey questions, reflecting >86% participation by individuals who met the eligibility criteria. Participants had the

option not to answer most of the questions; could occasionally make multiple selections from a provided list; and when necessary, could enter different answers.

Survey respondents were most likely to own the property with a well, be >45 years, and identify as White residents of Boulder County. While median household income in 2023 for Boulder County was estimated at \$103,000, the distribution for responses skewed toward higher income categories, with 35.5% of study participants reporting incomes >\$150,000 (Data USA, 2025). The most frequently reported level of completed education was a graduate degree (49.8%), and 16.5% of survey participants reported having children in the home. Detailed population demographic distribution results are available in Table 1.

Overall, two thirds of respondents reported having their water tested in the past, although further questions revealed that only 8.2% tested their water in the prior year, and even fewer (2.2%) responded that they test their well water annually. The most frequent reason for testing was to ensure that the water is safe to drink. Table 2 presents data for testing and treatment stratified by income group, and although the data in our study do not indicate statistical significance for whether or not someone has ever tested their water, it was found to be approaching a significant difference ($p = .06$). Significant differences were identified by education level, with the high school/GED group reporting the lowest likelihood of having ever tested their water ($p = .002$; Supplemental Table S1).

When asked what would motivate participants to perform more frequent testing, 88.2% of participants said free or discounted testing, 65.6% stated convenient drop-off/collection of samples, and 39.7% said annual reminders would help them remember to test their well water. When specifically asked why they did not test their water, 6.4% said they forgot. In response to questions about testing motivation mechanisms, higher-income participants reported a stronger desire for all three forms of assistance than lower-income groups, with statistically significant findings between income groups for both easy drop-off/collection ($p = .01$) and annual reminders ($p < .001$; Table 3). Moreover, the role of annual reminders as a motivator was statistically significant by education level (Supplemental Table S2).

More than 80% of respondents reported having concerns about water hardness and potential contaminants, with the highest frequencies reported for water hardness (51.6%); bacteria, viruses, and parasites (38.2%); uranium and other radioactive elements (33.8%); iron (24.7%); lead (23.7%); arsenic (23.2%); per- and polyfluoroalkyl substances (PFAS, 22.3%); pesticides (16.6%); copper (15.8%); nitrates/nitrites (15.6%); and fluoride (8.8%; Supplemental Table S3). The only contaminants for which differences in concern by income group existed were uranium and other radioactive elements, with the lowest income group reporting the highest likelihood of concern at 52.6% ($p = .05$).

Slightly under one half of respondents (48%) reported previous testing for total coliforms and *E. coli*, with 13% reporting that testing had identified issues with bacteria in prior tests. When participants tested their water, hardness was tested by 38.4% and identified for 20.6% of participants. Uranium was identified for 9.5% and iron for 7.1% of participants. Most other contaminants were reported as having previously been tested by approximately one quarter of participants, with rare identification of issues. Full data on water quality concerns, prior testing, and prior issue identification are shown in Supplemental Table S3.

Nearly one half of participants (45.5%) reported treating their water, whereas only 37.4% of participants performed recommended system maintenance, with significant differences identified among income groups ($p = .003$ for treatment, $p = .002$ for maintenance; Table 2). The highest income participants were most likely to both treat their water and maintain systems on the recommended schedule. Among participants reporting testing within the last year, 56.1% treated their water.

Likewise, among participants reporting testing their well water within the last 1–5 years, 57.5% treated their water. Among participants reporting never testing their water, only 34.0% used some type of water treatment system, which represents a statistically significant difference compared with 52.1% of participants who have tested their well water ($p < .001$). Among participants with no concerns about their water, 39.1% reported treating their water. The

TABLE 1

Descriptive Demographic Statistics for Study Participants ($N = 802$)

Demographic	#	% Total
Relationship to the property		
Own	703	87.7
Rent	5	0.6
Vacation home	78	9.7
Missing/other	16	2.0
Age (years)		
18–28	3	0.4
29–44	107	13.3
45–64	276	34.4
>65	371	46.3
Missing/prefer not to say	45	5.6
Race/ethnicity		
American Indian/Alaska Native	1	0.1
Asian	8	1.0
Black/African American	0	0
Hispanic/Latino	15	1.9
Middle Eastern/North African	4	0.5
Native Hawaiian/Pacific Islander	2	0.2
White	691	86.2
Missing/other/prefer not to say	59	7.4
Estimated 2023 annual household income		
<\$30,000	19	2.4
\$30,000–\$74,999	98	12.2
\$75,000–\$149,999	208	25.9
>\$150,000	285	35.5
Prefer not to say	154	19.2
Missing	38	4.7
Highest level of education completed		
High school/GED	8	1.0
Technical or community college	30	3.7
Some college	53	6.6
Bachelor's degree	215	26.8
Some graduate school	53	6.6
Graduate degree	399	49.8
Prefer not to say	7	0.9
Missing	37	4.6
Children present in the home		
≤17 years	132	16.5
≤5 years	45	5.6
<i>Note.</i> Race/ethnicity values do not sum to 100 because study participants could select none, one, or multiple categories.		

TABLE 2

Bivariate Statistics for Selected Data on Water Testing and Treatment Behaviors Overall and by Income Group

Testing and Treatment Behavior	Participants (N = 802) # (%)	Income Category of Survey Respondents (n = 764)					p-Value
		<\$30,000 (n = 19) # (%)	\$30,000– \$74,999 (n = 98) # (%)	\$75,000– \$149,999 (n = 208) # (%)	>\$150,000 (n = 285) # (%)	Prefer Not to Say (n = 154) # (%)	
Have ever had their well water tested	535 (66.7)	9 (47.4)	66 (67.3)	152 (73.1)	186 (65.3)	103 (66.9)	.06
Last time the well water was tested							.14
<1 year	66 (8.2)	2 (10.5)	8 (8.2)	13 (6.3)	28 (9.8)	12 (7.8)	
1–5 years	207 (25.8)	3 (15.8)	19 (19.4)	54 (26.0)	80 (28.1)	38 (24.7)	
>5 years	256 (31.9)	4 (21.1)	39 (39.8)	83 (39.9)	78 (27.4)	50 (32.2)	
Missing data	273 (34.0)	10 (52.6)	32 (32.7)	58 (27.9)	99 (34.7)	54 (35.1)	
Last time the septic tank was pumped							.12
<1 year	202 (25.2)	5 (26.3)	27 (27.6)	47 (22.6)	72 (25.3)	46 (29.9)	
1–5 years	451 (56.2)	11 (57.9)	47 (48.0)	130 (62.5)	163 (57.2)	78 (50.6)	
≥6 years	90 (11.2)	2 (10.5)	17 (17.3)	20 (9.6)	30 (10.6)	20 (12.9)	
Never	36 (4.5)	1 (5.3)	5 (5.1)	9 (4.3)	16 (5.6)	3 (1.9)	
Treat their well water	357 (46.7)	9 (47.4)	29 (29.6)	94 (45.2)	159 (55.8)	66 (42.9)	.003
Frequency at which the recommended maintenance of the treatment system is done							.002
Rarely or never	8 (1.0)	0	0	2 (1.0)	6 (2.1)	0	
Less often	50 (6.2)	1 (5.3)	2 (2.0)	12 (5.8)	27 (9.5)	7 (4.5)	
As recommended	300 (37.4)	7 (36.8)	26 (26.5)	79 (38.0)	124 (43.5)	59 (38.3)	
Missing data	444 (55.4)	11 (57.9)	70 (71.4)	115 (55.3)	128 (44.9)	88 (57.1)	

Note. Testing for differences between income groups was conducted using chi-square statistics. Percentages were calculated within each income group to allow for cross-group comparison. Survey participants who did not respond to the income question (n = 38) were excluded from the income-based analysis.

percentage of study participants reporting each type of treatment option is shown in Figure 1.

In terms of appropriateness of treatment, for almost all potential water issues, use of treatment methods that would address identified concerns was higher among participants who reported that prior testing identified issues with specific contaminants than among participants who were concerned about contamination in general (Supplemental Table S4). This finding indicates that testing and prior identification of problems with water increases the likelihood that households will select appropriate treatment modalities. A notable exception to this trend is for lead: Compared with households simply reporting concerns about lead, households with identified lead

contamination issues are properly treating their water less frequently. Specific contaminant treatment data are available in Supplemental Table S4.

Most respondents reported that they would use free water resources and programming (70.1%), support resource development (84.4%), and wanted free water testing as part of our study (91.1%). Significant differences by education level were identified in knowledge about where to find well stewardship information, indicating the need for better access to resources and information ($p < .001$).

Given the potential for contamination of well water systems by failing or undermaintained septic systems (Table 2), we added information about inspection and maintenance of septic systems to our workshop programming.

Discussion

Our study identified several key concerns and potential opportunities for developing further resources and more robust communication about well stewardship. Although CDC (2025a) recommends annual testing of well water for bacteria, nitrates, total dissolved solids, and pH level, only 8.2% of study participants reported annual testing, similar to the 10% reported in a study of well users in Wisconsin (Malecki et al., 2017). Both estimates, however, fall far below the 35% estimate from a study in Ontario, Canada, where bacterial testing is offered for free (Kreutz-wiser et al., 2011). This discrepancy suggests that a potential mechanism to increase testing in well water users would be offering free or discounted testing. This suggestion is also aligned with our survey data, which indicate

TABLE 3

Bivariate Statistics Showing Selected Data on Beliefs and Motivating Factors About Water Knowledge, Testing, and Treatment by Income Group

Belief and Motivating Factor	Income Category of Survey Respondents (n = 764)						p-Value
	Participants (N = 802) # (%)	<\$30,000 (n = 19) # (%)	\$30,000–\$74,999 (n = 98) # (%)	\$75,000–\$149,999 (n = 208) # (%)	>\$150,000 (n = 285) # (%)	Prefer Not to Say (n = 154) # (%)	
Free or discounted testing would increase my testing frequency	674 (88.2)	15 (78.9)	90 (91.8)	190 (91.3)	245 (86.0)	134 (87.0)	.17
Collection of sample and/or convenient drop-off would increase my testing frequency	501 (65.6)	8 (42.1)	53 (54.1)	139 (66.8)	202 (70.9)	99 (64.3)	.01
Annual testing reminders would increase my testing frequency	303 (39.7)	5 (26.3)	31 (31.6)	82 (39.4)	142 (49.8)	43 (27.9)	<.001
If free programs for water education and support were developed, I would use them	549 (71.8)	15 (78.9)	58 (59.2)	163 (78.4)	211 (74.0)	101 (65.6)	.01
I believe that regular water quality testing is important for safety	639 (83.6)	14 (73.7)	79 (80.6)	182 (87.5)	237 (83.2)	127 (82.5)	.69
My health would be negatively impacted by drinking untreated well water	374 (49.0)	7 (36.8)	38 (38.8)	94 (45.2)	153 (53.7)	82 (53.2)	.19
If a water quality test found an issue with my well water, I would take steps to address the issue	735 (96.2)	19 (100)	90 (91.8)	199 (95.7)	278 (97.5)	149 (96.8)	.11
I believe that well testing requirements are effective ways to ensure water safety	580 (75.9)	9 (47.4)	61 (62.2)	160 (76.9)	230 (80.7)	120 (77.9)	<.001
I am confident I know how to select the proper water treatment option	418 (54.7)	8 (42.1)	49 (50.0)	115 (55.3)	155 (53.7)	93 (60.4)	.47
I know how to ensure water safety after an emergency (e.g., flood, fire)	483 (63.2)	11 (57.9)	61 (62.2)	138 (66.3)	171 (60.0)	102 (66.2)	.27
I want to learn more about how to protect my well and water safety	680 (89.0)	18 (94.7)	8 (86.7)	190 (91.3)	254 (89.1)	133 (86.4)	.11
I know where to find more information about well management and water treatment	412 (53.9)	9 (47.4)	56 (57.1)	118 (56.7)	140 (49.1)	89 (57.8)	.05
I know how to get my well water tested	539 (70.5)	14 (73.7)	65 (66.3)	151 (72.6)	196 (68.8)	113 (73.4)	.78

Note. Testing for differences between income groups was conducted using the chi-square test. Percentages were calculated within each income group to allow for cross-group comparison. Survey participants who did not respond to the income question (n = 38) were excluded from the income-based analysis.

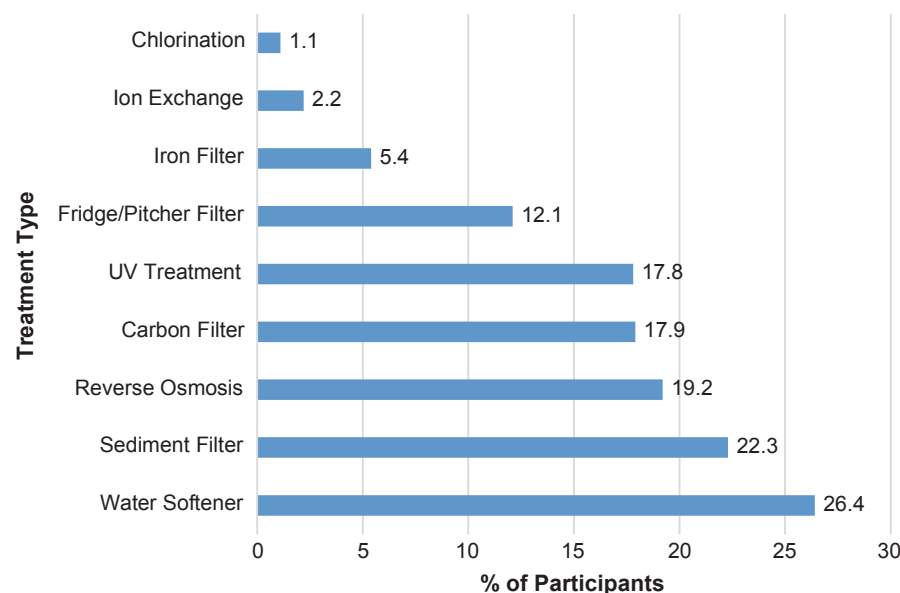
that many respondents would test more frequently if testing were free.

Although no statistical significance was identified for whether income levels were associated with having ever tested their

water, that finding approached significance. This finding is important to mention for two reasons. First, we found that the lowest income group had the lowest prevalence of ever having had water tested at 47.4%,

whereas all other income categories had ever tested at 65% or higher, which indicates that the lowest income group here is also the most likely to have never tested their water. Second, this income group was

FIGURE 1

Reported Types of Water Treatment

Note. Some participants reported using multiple treatment modalities.

underrepresented in the dataset, with only 19 observations reporting this income range. Although we had strong overall enrollment in our study, the small sample size in this income category might have contributed to the lack of statistical significance. As a result of this finding, we have engaged in targeted outreach to lower-income populations and renters to better understand their water testing behaviors.

Prior water testing is associated with well water treatment, as the overall prevalence of treating water (45.5%) falls between the stratified rates for participants who have never tested their water (34.0%) and participants who have tested their water (52.1%). Income group differences were statistically significant, but education levels were not. The below-median income group (\$30,000–\$74,999) reported the lowest rate of treatment, which could indicate that cost is a motivating factor. Additionally, the highest income groups were most likely to maintain their water treatment systems according to recommendations.

For the 39.1% of participants who reported no water quality concerns and who were actively treating their water, it is impossible

to determine if they lacked concerns because they were reassured by their current water treatment or if there was a disconnect between their concerns and their actual behavior related to water treatment. This question should be explored in future studies.

Survey results point to potential areas for improvement in future interventions to increase the prevalence of well water testing. Suggestions include free or subsidized water testing, annual reminders, and better accessibility to water sample drop-off locations. Equally important is providing and promoting information about where and how to obtain water testing and support for well stewardship; this information ideally would be via partnerships between well users and governmental health and water agencies (Kreutzweiser et al., 2011; Lavalley et al., 2023).

In our study, we found that the most common water quality concerns and treatment methods employed were generally aligned, with participants most frequently responding that they were concerned about water hardness, microorganisms, uranium, and other radioactive elements. Further, participants most frequently responded that they used water softening and reverse osmosis systems.

We found that participants who had prior water issues identified through testing were more likely to use water treatment systems to address those concerns, although there is substantial room for improvement in the alignment of concerns and treatment modalities. Overall, study participants expressed similar concerns about contaminants, with the notable exception of uranium, which was a more prevalent concern among the lowest-income group. This finding aligns with other studies that examined the connection between beliefs about radiation and income levels (Fukasawa et al., 2022).

Emerging concerns among participants in our study included worry about the stability of their water supply, the impacts of floods and droughts, and the potential for contamination of well water from wildfires and the chemicals used to fight those fires. The 2021 Marshall Fire in Boulder County was mentioned by multiple study participants as a specific contamination concern (NOAA Research, 2024). Given the demonstrated link between precipitation and microbial well water quality (Invik et al., 2019; Rowles et al., 2020; Stallard et al., 2021); wildfires and contamination of private wells and source water for public drinking water supplies in Colorado (Jankowski et al., 2023; U.S. Geological Survey, 2012); and documented increases in fire activity in the region (Barbier & Gifford, 2025), we are considering future workshop breakout sessions focused on concerns related to climate change.

Strengths of our study include the overall sample size and the high response rate. This success could be due, in part, to our sampling strategy of contacting septic permit users directly, rather than relying on general advertising. This sampling strategy was helpful in reducing selection bias that could result from targeted recruitment, because our strategy reached many potential well users.

Some limitations of our study include the use of self-reported survey data and occasional mismatches in how questions were asked, which limits our ability to draw conclusions in some facets. Mailing information to septic permit holders could have skewed the sample to homeowners, which might have contributed to underrepresentation of renters. Additionally, the short time window for study participation might have contributed to selection bias, as our study popula-

tion did not fully reflect the demographics of Boulder County, although our study population could potentially be more representative of the county's well users.

Moreover, we did not collect information on either address or general location (e.g., mountain, outskirts of town, city) of each participant, which would have been helpful information in ensuring adequate representation of all potential well users. It is also possible that there were well users who were unwilling to participate due to not wanting to share information, fear of negative effect on property values, or other concerns unrelated to well water stewardship.

Conclusion

Several areas of our study identified differences in user behaviors related to well water testing, treatment, and system maintenance by income level, which supports the need for the creation of additional resources directed toward lower-income groups. Ongoing components of this study include a series of participant interviews as well as water sample analysis to determine the prevalence of contaminants. The samples are tested for total coliforms, *E. coli*, arsenic, cadmium, iron, manganese, nitrates, and uranium.

The potential exists for future comparison with historical assessments of regional

groundwater, depending on the location of the wells. We will share our water testing results with the participating individual well users, along with information on health implications and mitigation strategies. Additional data surrounding well water risk factors are being collected and will be studied to determine specific risk factors associated with well contamination.

After our first workshop, all partners met for a discussion about what went well, what could be improved, and where we could add programming to suit the needs of attendees. We are planning to host a series of four water stewardship workshops in rural and urban areas of Boulder County, with future articles documenting the iterative planning, development, and revision process. Topics to be covered in the workshops include well inspection, well water testing recommendations and interpretation of results, common sources of contamination, and treatment modalities. We intend to collect data to measure knowledge around well stewardship before and after the workshops to determine the effectiveness of our messaging.

Participants who expressed interest in additional data collection were invited to one-on-one interviews where a member of our study team asked the participant about well management in greater detail. The objective of these interviews is to further

understand the perceptions of well water quality, the risks of well water consumption, and the motivations and challenges to practices related to well management. Our findings will be included in a future article reporting on the results of these individual qualitative interviews.

Efforts to ensure safe access to drinking water for well users require reliable information about well water testing and treatment, affordable and available water testing, and feasible modalities for appropriate water treatment. These efforts might also benefit from more robust public health partnerships. ✨

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