Predictors of Water Lead Levels in Drinking Water of Homes With Domestic Wells in 3 Illinois Counties

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ABSTRACT

Context: Millions of US homes receive water from private wells, which are not required to be tested for lead (Pb). An approach to prioritizing high-risk homes for water lead level (WLL) testing may help focus outreach and screening efforts, while reducing the testing of homes at low risk.

Objective: To (1) characterize distribution of WLLs and corrosivity in tap water of homes with private residential wells, and (2) develop and evaluate a screening strategy for predicting Pb detection within a home.

Design: Cross-sectional.

Setting: Three Illinois counties: Kane (northern), Peoria (central), and Jackson (southern).

Participants: 151 private well users from 3 Illinois counties.

Intervention: Water samples were analyzed for WLL and corrosivity.

Main Outcome Measures: (1) WLL and corrosivity, and (2) the sensitivity, specificity, and predictive value of a strategy for prioritizing homes for WLL testing.

Results: Pb was detected (>0.76 ppb) in tap water of 48.3% homes, and 3.3% exceeded 15 ppb, the US Environmental Protection Agency action level for community water systems. Compared with homes built in/after 1987 with relatively low corrosivity, older homes with more corrosive water were far more likely to contain measurable Pb (odds ratio = 11.07; 95% confidence interval, 3.47-35.31). The strategy for screening homes with private wells for WLL had a sensitivity of 88%, specificity of 42%, positive predictive value of 58%, and negative predictive value of 80%.

Conclusions: Pb in residential well water is widespread. The screening strategy for prioritizing homes with private wells for WLL testing is greater than 85% sensitive.

KEY WORDS: corrosivity, housing, lead, Pb, rural health, screening programs, water, well

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Lead (Pb) exposure is associated with many health effects such as neurodevelopmental impairment, distractibility, impulsivity, shortened attention span, and reduced IQ.[1-7] The American Academy of Pediatrics states that no level of Pb exposure is safe, so Pb exposure in children should be prevented.[8] Widespread Pb exposure in community water systems of Flint, Michigan;[9] Washington, District of Columbia;[10] Montreal, Canada;[11] and Newark, New Jersey[12] brought this issue into the public eye. Private wells pump water from aquifers

directly into homes, rather than through a centralized treatment facility and water distribution system. Private wells are largely a rural phenomenon.[13-15] Unlike community water systems, regulated under provisions of the Safe Drinking Water Act, private well water quality is not regulated by federal law and only 17 states require testing for coliform bacteria and nitrate after well construction, but Pb testing is not required.[16] While several states require water Pb testing prior to the sale of a home on a community water system, only Rhode Island, to the best of our knowledge, requires Pb testing in well water for real estate transactions. Testing for Pb in private well water is rarely required and infrequently initiated by homeowners.[17,18]

Several studies have evaluated water lead levels (WLLs) in private wells in Pennsylvania,[17] Wisconsin,[19] Virginia,[20] New York,[21] and North Carolina,[22] reporting fairly widespread Pb contamination in private well water, ranging from 1.8% to 19% above 15 parts per billion (ppb)—US Environmental Protection Agency's (US EPA's) "action level" for Pb in public drinking water systems. The median WLL reported in these studies ranged from 1.57 to 9 ppb. Many elements of private wells can contain Pb (eg, casing, pipes, packers, and fixtures),[23] as can home plumbing (eg, solder, brass, pipes, and plumbing fixtures).[24] The source of Pb is not thought to be the water source (in this case, aquifers) but rather the leaching or migrating of Pb from pipes and plumbing into corrosive water. Nevertheless, only one of the studies of private well WLLs has included water corrosivity measures (chloride (Cl^-) and the chloride-sulfate mass ratio [CSMR]), though this was a focused study conducted near a road salt storage barn.[21]

Despite evidence that Pb in drinking water of homes threatens public health, specifically households with pregnant women and small children who are already more susceptible to Pb-induced health effects, federal requirements and funding for testing WLLs in the millions of homes with private wells are nonexistent.[25,26] Given the estimated 13 million private wells in the United States serving approximately 44 million people, a strategy to identify and test homes at an increased risk is needed to focus outreach efforts and reduce testing of homes at low risk,[14,15] as well as the evaluation of the sensitivity, specificity, and predictive value of such a strategy.

The primary aims of this research were to (1) characterize the distribution of WLLs and water corrosivity in tap water of homes with private wells in 3 Illinois counties, and (2) develop and evaluate a screening strategy for predicting Pb detection within a given home.

Methods

Study design

In this cross-sectional study, tap water samples were analyzed for WLL and corrosivity and a questionnaire was provided to participants (n = 151). Next, 37 households with the highest WLLs were asked to provide a second set of tap water samples, which in addition to WLL and corrosivity were analyzed for copper and a broader suite of chemical parameters.

Study settings and groundwater conditions

The study took place in 3 Illinois counties: Kane, Peoria, and Jackson. Illinois is estimated to have approximately 680 000 private wells serving more than 2 million Illinoisans (W. Kelly, PhD, electronic communication, July 17, 2020). Kane, Peoria, and Jackson Counties have approximately 18 000, 7100, and 1900 private wells, respectively. Kane County is approximately 50 miles west of Chicago in northern Illinois and has about 530 000 residents, about 11% of housing units are rural, and 50.5% of housing was built before 1980.[13] Peoria County in central Illinois has a population of about 180 000 residents, about 17% of housing units are rural, and more than 75% of houses are pre-1980. Jackson County, in southern Illinois, has about 57 000 residents, more than 30% of housing units are rural, and 60% of housing was built prior to 1980.[13] Groundwater conditions differ significantly across counties. Shallow groundwater resources are abundant in Kane County, including unconsolidated sand and gravel glacial deposits and underlying shallow bedrock less than 300 ft beneath land surface.[27-30] In Peoria County, domestic wells are typically found in sand and gravel glacial deposits, with the most productive aquifers along the Illinois River.[31] Jackson County has productive sand and gravel, sandstone, and limestone aquifers,[32] with creviced limestones and karst features present in the southwestern part of the county.[33,34]

Groundwater in Kane and Peoria Counties is typical of shallow groundwater in the glaciated Midwest, that is, moderate to strongly reducing conditions and abundant carbonate alkalinity. Shallow groundwater in many parts of Kane County, especially in urbanized areas, has elevated Cl^- levels due primarily to road salt runoff.[35] Groundwater in the shallow karst aquifers in Jackson County tends to be more dilute than other shallow aquifers due to relatively rapid movement of water into and through the subsurface; they are vulnerable to surface contamination from septic systems.[32,36,37]

Participant enrollment

Local health department (LHD) environmental health staff played a central role in participant recruitment and enrollment, as well as in teaching participants procedures for collecting and shipping water samples. Participants were recruited through press releases, social media content, and flyers distributed in various public meetings and other public locations and through walk-in LHD traffic. Individuals who expressed interest in the study were evaluated for eligibility, namely, whether they lived in the county and in a home served by a private well. LHD staff taught water sampling methods to participants, and a video of water sampling technique was available in English and Spanish (http://privatewellclass.org/lead-sampling). Institutional Review Board approval was obtained from both University of Illinois and Northern Illinois University, and all participants provided written informed consent. LHD staff working on the project were trained in human subjects research.[38]

Water sampling

Participants were provided with 2 acid-washed and rinsed, 1-L, high-density polyethylene sample bottles, nitrile gloves, a freezer pack, a preaddressed Styrofoam shipping container, sampling instruction sheet, and a questionnaire.[39] They were instructed to collect from the kitchen tap a first-draw sample after at least 6 hours of stagnation, consistent with the requirements of the Lead and Copper Rule (LCR).[40] After discarding the next 5 L of water, the seventh-liter (flushed) sample was collected in the second sample bottle.[41] The 2 sample bottles were placed into an insulated shipping container with the freezer pack and the completed questionnaire and shipped to the Illinois State Water Survey Public Service Laboratory for analysis. Results were mailed directly to participants, along with information about contacting their LHD about further Pb testing, children's health, and mitigation.

Of the 37 households with the highest WLLs (~12 per county), 28 agreed to participate in repeat WLL testing for an overall response rate of 75.7%. All households that underwent repeat WLL testing had initial WLL concentrations of 2 ppb or more. The protocol for home water sampling was identical at baseline and on repeat testing. In addition, research team members collected well samples from an outside spigot or hydrant that had been turned on for at least 10 minutes.

Analytical techniques

Details of laboratory analyses methods are available in Supplemental Digital Content (available at http://links.lww.com/JPHMP/A718). In brief, Pb and copper were analyzed using US EPA Method 200.9.[42] The minimum detection limit and limit of quantification for this method was 0.76 ppb. Samples were preserved with 0.2% nitric acid and subsequently digested in 3% nitric acid before analysis. Measurements were made using an Agilent Technologies 240Z Graphite Furnace Atomic Absorption Spectrometer, with Zeeman background correction.

Corrosivity was calculated in 2 ways. The Larson-Skold Index (LSI) was calculated as follows[43]:

$$LSI = \frac{(epm\ Cl^- + epm\ SO_4^{2-})}{(epm\ CaCO_3)} \qquad [\text{Equation 1}]$$

where epm refers to equivalents per million.

The CSMR[44] was calculated as the ratio of Cl$^-$ to SO$_4^{2-}$ in mg/L.

Questionnaire

A 32-item questionnaire was developed on the basis of existing national surveys as well as those used in previous published research (see Supplemental Digital Content, available at http://links.lww.com/JPHMP/A718).[13,45-50] The questionnaire included items on demographics, housing and well characteristics, water consumption and use, and water quality perceptions. Paper questionnaires were included in the sampling kit that participants received and returned in the kit with their water samples. Questionnaire data were manually entered in duplicate. Data entry discrepancies were adjudicated by the principal investigator.

Statistical analysis

Chemistry data with nondetection results were replaced with a value of the sample quantification limit divided by the square root of 2.[51,52] Statistical analyses were conducted using SAS 9.4 (SAS Institute, Cary, North Carolina) and SigmaPlot version 11.0 (Systat Software, San Jose, California). Univariate analyses and evaluations of normality were conducted for WLLs, physicochemical parameters, LSI, CSMR, and questionnaire responses. Three sets of single predictor logistic models of WLL were conducted with 3 different dichotomous outcomes: detection, 2 ppb or more, and 5 ppb or more, where detection = 0.76 ppb. To evaluate whether observed associations between

WLLs and other variables were due to the cut points chosen for Pb, we conducted sensitivity analyses using various definitions of the dichotomous corrosivity and housing age predictor variables.

Logistic regression models of the association between housing and/or corrosivity variables, and WLL (detection vs nondetection, <2 ppb vs ≥2 ppb, <5 ppb vs ≥5 ppb) were conducted and stratified by housing age category, using "built in or before 1986" versus "built later" as the cut point, based on the 1986 revisions to the Safe Water Drinking Act that reduced Pb content of plumbing materials.[53] Other cut points such as 1991 (when the LCR was published) were also explored.[40] On the basis of logistic regression modeling, simple decision rules were evaluated to identify homes at high risk for having detectable Pb, as well as WLLs 2 ppb or more or 5 ppb or more. Odds ratios (ORs), 95% confidence intervals (CIs), and $\alpha = 5\%$ described associations. The cut points of key predictor variables strongly associated with WLL detection (ie, with relatively large ORs) were the basis for developing the screening strategy.

To characterize the performance of the screening strategy, we calculated sensitivity, specificity, positive predictive value, and negative predictive value. WLL and corrosivity data were complete, though estimated age of home was missing for 8 of 151 (5.3%) homes and was not imputed but excluded from the analysis.

Results

Demographics and housing

Of the 151 participating households, all provided water samples and 150 completed questionnaires (99.3%). Table 1 shows descriptive characteristics of study participants, wells, and housing. Median self-reported well depth across counties was about 172 ft (IQR = 65-300). More than half had an older (1986 and earlier) well, whereas about 63% had an older (1986 and earlier) home.

Water quality

Measurable Pb was found in 73 (48.3%) and 34 (22.5%) stagnant and flushed samples, respectively. WLL exceeded the EPA 15 ppb standard that applies to community water systems in 5 (3.3%) stagnant samples and none of the flushed samples. Further details about dissolved versus total Pb are given in Supplemental Digital Content, Table 1 (available at http://links.lww.com/JPHMP/A718).

Associations between corrosivity and lead in older and newer homes

Table 2 summarizes bivariate associations between corrosivity and WLL. Various definitions of housing age and corrosivity were associated with both WLL cut points (≥0.76 and ≥2 ppb). Associations between corrosivity and WLLs 5 ppb or more and between housing age and WLLs 5 ppb or more did not reach statistical significance, as relatively few households had WLLs in that higher range (data not shown). While the LSI was associated with WLL, other measures of corrosivity (CSMR, Cl⁻, or alkalinity) were not.

Table 3 shows results of logistic modeling of 3 dichotomous WLL categories. Among older homes (built post-1986), LSI values above 0.63 (the 75th percentile value for our study sample) were associated with increased odds of WLLs 2 ppb or more; the same was true for WLLs 5 ppb or more. LSI was not associated with increased odds of WLL detection or WLLs 2 ppb or more among newer homes. Logistic regression analysis showed that compared with a referent category of newer homes (built in/after 1986) with low corrosivity (<75th LSI percentile), newer homes with high corrosivity (≥75th LSI percentile) had an OR of 1.94 for Pb detection, but this association did not reach significance. Compared with newer homes with low corrosivity, both old homes with low corrosivity (OR = 4.68; 95% CI, 1.86-11.73) and old homes with high corrosivity (OR = 11.07; 95% CI, 3.47-35.31) were significantly associated with increased odds of Pb detection.

Screening strategy development and performance characteristics

Given the strong associations among corrosivity, housing age, and WLLs, these were used in the screening strategy. Rather than using corrosivity on a continuous scale, dichotomous cut points were used because (1) LSI values are not routinely reported in national reports of groundwater corrosivity at the state or local level, and (2) a dichotomous decision rule would be easier to apply than one that required use of regression coefficients. Based on the aforementioned facts, the 2 components of the decision were (1) home built before 1987 and (2) LSI greater than 0.63.

Table 4 shows sensitivity and specificity of 2 variations of the screening strategy that may be useful for prioritizing homes for WLL testing. Using a rule of "old home AND corrosive water" yielded higher specificity and lower sensitivity than a rule defined as

TABLE 1
Descriptive Characteristics of Residents and Wells

Question/Item	Kane, n (%) or Median (IQR)	Jackson, n (%) or Median (IQR)	Peoria, n (%) or Median (IQR)	Total, n (%) or Median (IQR)
Total number of participants	62	38	51	151
Resident factors				
Female	29 (46.8)	13 (35.1)	14 (27.5)	56 (37.3)
Respondents	57 (92.9)	34 (89.5)	43 (84.3)	134 (89.3)
Race/Ethnicity				
Non-Hispanic White	51 (82.3)	34 (91.9)	43 (84.3)	128 (85.3)
Non-Hispanic Black	2 (3.2)	0 (0.0)	0 (0.0)	2 (1.3)
Hispanic	1 (1.6)	0 (0.0)	1 (2.0)	2 (1.3)
Other	1 (1.6)	0 (0.0)	1 (2.0)	2 (1.3)
Respondents	55 (88.7)	34 (89.5)	45 (88.2)	134 (89.3)
Age, y				
26-45	3 (4.8)	2 (5.4)	5 (9.8)	10 (6.7)
46-65	11 (17.7)	7 (18.9)	7 (13.7)	25 (16.7)
$\geq$66	24 (38.7)	19 (51.4)	22 (43.1)	65 (43.3)
Respondents	38 (61.3)	28 (73.7)	34 (66.7)	100 (66.7)
Education				
Some high school	0 (0.0)	1 (2.7)	1 (2.0)	2 (1.3)
High school graduate	6 (9.7)	5 (13.5)	9 (17.6)	20 (13.3)
College/university graduate	14 (22.6)	8 (21.6)	14 (27.5)	36 (24.0)
Postgraduate degree	17 (27.4)	8 (21.6)	13 (25.5)	38 (25.3)
Respondents	37 (59.7)	22 (57.9)	37 (72.3)	96 (64.0)
Annual income, $				
<25 000	1 (1.6)	3 (8.1)	1 (2.0)	5 (3.3)
25 000-54 999	2 (3.2)	6 (16.2)	6 (11.8)	14 (9.3)
$\geq$55 000	39 (62.9)	20 (54.1)	31 (60.8)	90 (60.0)
Respondents	42 (67.7)	29 (76.3)	38 (74.5)	109 (72.7)
Well and housing factors				
Well construction				
Drilled	33 (53.2)	29 (78.4)	26 (51.0)	88 (58.7)
Bored	0 (0.0)	1 (2.7)	7 (13.7)	8 (5.3)
Other	0 (0.0)	3 (8.1)	3 (5.9)	6 (4.0)
Respondents	33 (53.2)	33 (86.8)	36 (70.6)	102 (68.0)
Well depth, ft	235.0 (230)	200.0 (217)	60.0 (58)	172.5 (236)
Respondents	37 (60.0)	29 (76.3)	36 (70.6)	102 (68.0)
Year house was built[a]	1977 (1964-1992)	1984 (1969-1994)	1978 (1958-1994)	1978 (1964-1993)
Respondents	58 (93.5)	35 (92.1)	49 (96.1)	142 (94.7)
Detectable water lead				
Stagnant samples	27 (43.5)	20 (52.6)	26 (51.0)	73 (48.3)
Flushed samples	8 (12.9)	11 (28.9)	15 (29.4)	34 (22.5)
Respondents	62 (100)	38 (100)	51 (100)	151 (100)

Abbreviation: IQR, interquartile range.
[a] Median (IQR).

TABLE 2
Single Predictor Models of Water Pb Detection and WLL ≥2 ppb

Predictor	Outcome: Pb Detection, OR (95% CI)	Outcome: WLL ≥2 ppb, OR (95% CI)
House built 1986 or earlier	5.18 (2.35-11.42)[a]	2.88 (1.16-7.16)[b]
House built pre-1964 (25th percentile)	1.42 (0.65-3.09)	0.41 (0.15-1.16)
House built pre-1978 (median)	2.22 (1.13-4.34)[b]	1.25 (0.59-2.63)
House built pre-1994 (75th percentile)	4.23 (1.82-9.81)[c]	3.07 (1.10-8.57)[b]
LSI (continuous)	1.95 (0.98-3.89)	2.14 (1.08-4.27)[b]
LSI ≥0.08 (25th percentile)	2.26 (1.03-4.95)[b]	2.19 (0.84-5.73)
LSI ≥0.23 (Median)	1.77 (0.93-3.38)	3.27 (1.49-7.18)[c]
LSI ≥0.63 (75th percentile)	2.38 (1.12-5.06)[b]	3.32 (1.52-7.23)[c]

Abbreviations: CI, confidence interval; LSI, Larson-Skold Index; OR, odds ratio; Pb, lead; WLL, well lead level.
[a]P < .001.
[b].01 ≤ P < .05.
[c].0001 < P <.01.

TABLE 4
Sensitivity and Specificity of Screening Tool

	Old Home AND Corrosive Water	Old Home OR Corrosive Water
Sensitivity	0.30	0.88
Specificity	0.90	0.42
Positive predictive value	0.74	0.58
Negative predictive value	0.59	0.80

samples of a given home (*P* values all >.4). Cl⁻ concentrations were much higher in Kane and Peoria County samples than in Jackson County.

Jackson County samples collected at follow-up suggested rapid recharge into the shallow karst aquifer. Most of the samples had measurable dissolved oxygen, and nitrate and Cl⁻ concentrations greater than background.[54,55] Of the 9 follow-up samples from Jackson County, 5 had pH values less than 6.0. Although pH is not explicitly considered in either LSI or CSMR, low pH waters are clearly corrosive and first-draw WLLs were correlated with pH for follow-up sampling in Jackson and Kane Counties (see Supplemental Digital Content, Figure 2, available at http://links.lww.com/JPHMP/A718).

"old home OR corrosive water." Because sensitivity is more important than specificity to identify at-risk homes due to health risks of Pb exposure, the "or" criterion would be preferred.

Water lead levels on follow-up testing

Twenty-eight homes were resampled for Pb. For all sites, WLLs decreased from stagnant samples to flushed samples to well samples (Figure). Three well samples in Jackson County had detectable WLLs, suggesting well or pump components could be a Pb source.

Among homes with the highest initial WLLs in first-draw samples, follow-up first-draw WLLs were considerably lower (see Supplemental Digital Content, Figure 1, available at http://links.lww.com/JPHMP/A718). Mann-Whitney rank sum tests showed no significant differences between alkalinity, Cl⁻, sulfate, LSI, or CSMR between the initial and follow-up

Discussion and Conclusion

This is the first study to measure corrosivity as a predictor of WLLs in private wells from non–point sources of corrosive agents. Findings that 48.3% of homes tested had detectable Pb and that 3.3% had levels exceeding the US EPA action level that applies to community drinking systems are broadly consistent with findings elsewhere in the US Midwest and East Coast.[17,19-22] Among the 3.3% of samples with WLL more than 15 ppb, nearly all of the Pb present was in the particulate phase. This work points to a public health need for testing homes with private wells for Pb, and the screening strategy described here is a first start in that direction. Further research is

TABLE 3
Association Between Elevated Corrosivity (>75th Percentile LSI) and Dichotomous WLL, by Housing Age Category

Home Built	Pb Detection, OR (95% CI)	Pb ≥2 ppb, OR (95% CI)	Pb ≥5 ppb, OR (95% CI)
1986 and earlier	2.32 (0.86-6.21)	3.17 (1.24-8.06)[a]	4.50 (1.16-17.50)[a]
1987 and later	1.94 (0.40-9.49)	1.94 (0.31-12.12)	Unstable estimate

Abbreviations: CI, confidence interval; LSI, Larson-Skold Index; OR, odds ratio; Pb, lead; WLL, well lead level.
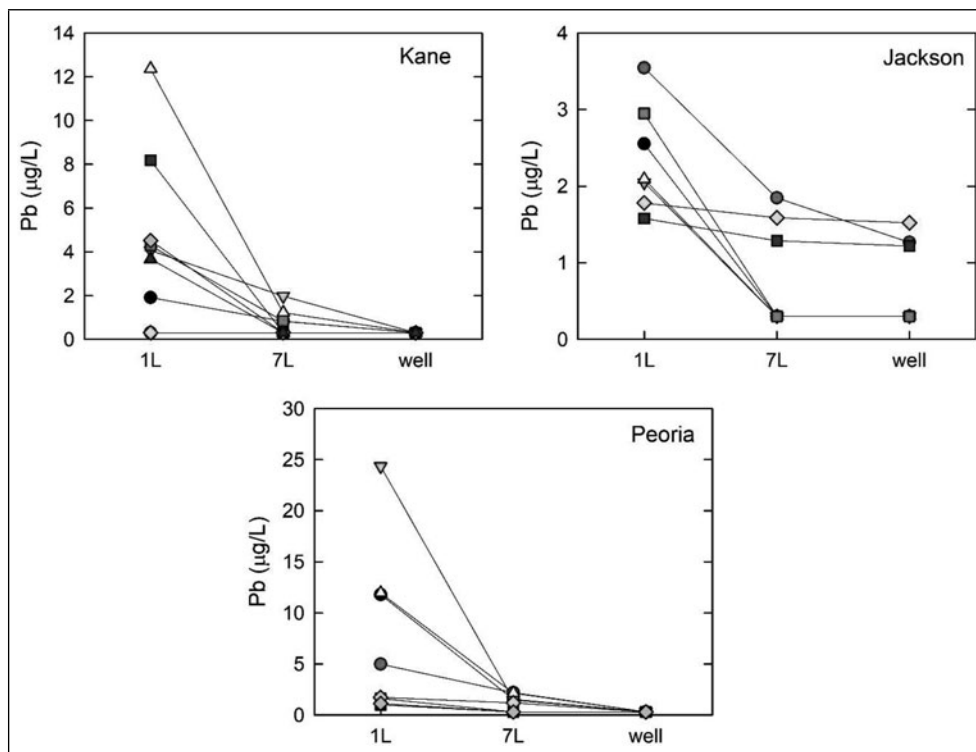[a]P < .05.

FIGURE Lead Concentrations in Stagnant (1st L), Flushed (7th L), and Well Samples in Follow-up Sampling[a]
[a]Except for 3 samples in Jackson County, Pb below detection level (<0.76 ppb) in all well samples.

needed to improve the sensitivity and specificity of this approach.

Given that 44 million people in the United States rely on private wells for drinking water,[13,14] identifying predictors of water Pb presence or elevation should be useful in identifying homes with private wells that are at an increased risk for Pb contamination. Home age (1986 and earlier, when the use of Pb in plumbing materials and service lines was banned, vs post-1986) and water corrosivity were found to be predictors of detectable WLLs. Home age can be determined through municipal records or estimated by homeowners. Maps of potential corrosivity of untreated groundwater have been published by the US Geological Survey and should be used by LHDs and others to determine whether corrosive groundwater is likely to be present locally.[56] LHDs could play a primary role in driving this process, but community-based organizations could be involved as well. Programs in Pennsylvania (Pennsylvania Master Well Owner Network) and Virginia (Virginia Household Water Quality Program and Virginia Master Well Owner Network) are examples of state extension programs that combined subsidized testing, education, and recommendations on mitigation, such as removal of Pb components, maintenance, and installation of treatment devices.[57,58] These programs may

still not reach socioeconomically disadvantaged individuals who are most at risk, as seen in other studies, without federal requirements and funding allocated to private well testing.[59-62]

At baseline, Pb in tap water of homes with the highest WLLs was generally in particulate form; those levels were much lower on follow-up testing (see Supplemental Digital Content Figure 1, available at http://links.lww.com/JPHMP/A718). This highlights the importance of improved understanding of physical and/or chemical processes associated with formation and intermittent release of particulate Pb in water systems, in addition to adequate treatment/filtration. It also raises the question of frequency of testing required to determine that intermittent release of particulate Pb is not occurring.

Jackson County has shallow carbonate (limestone and dolomite) aquifers that contain karst features such as sinkholes. Dissolution of bedrock has produced creviced aquifers connected to land's surface. Rainfall, which has a natural pH of 5 to 5.5, enters the aquifer and rapidly passes through the creviced bedrock, with little time to react with the bedrock or soil zones above it.[63] Thus, the water can be naturally corrosive. Low pH waters have been linked to high WLLs in other states.[17,20] Closer proximity of wells to recharge zones means more rapid water movement

and a higher likelihood of corrosive water. It seems possible, then, that WLLs may vary temporally in such terrains, as the groundwater flow and geochemistry vary as a result of variations in recharge.

Our study has several limitations. First, study participants, rather than members of the research team, conducted water sampling in their homes. We are unable to estimate the extent of sampling protocol adherence, although protocols were fairly simple. Results were consistent with our expectation, based on existing literature, that flushed water samples would have lower WLLs than stagnant samples, indicating protocol adherence. Second, participants were recruited by LHDs through publicity efforts and almost certainly do not represent a random sample of private well users within counties. It is not possible to evaluate whether the mean WLLs, demographics, or housing characteristics of participants would have been different had random sampling been used, which was not feasible in this pilot study. Representative sampling should be considered in future research. Given that

testing of WLLs in private wells is not required, it is unlikely that participants self-selected because of their knowledge of tap WLLs. Third, data about plumbing or well materials in homes were not collected. Efforts to screen homes for WLLs could be improved if the presence of Pb-bearing materials in plumbing or well elements was known. Fourth, because we were unable to identify a validated questionnaire specific to purposes of this study, we developed one, in part, drawing items from questionnaires used by others. Fifth, this study included 3 of the 102 counties in Illinois, representing 3 distinct groundwater regions. Observed prevalence of WLL detection and associations between WLL and corrosivity may differ in other settings.

Study results indicate that approximately half of homes in this study had measurable WLLs and that 3.3% had levels that exceeded the 15-ppb level that applies to community water systems.[64] This is a clear threat to the health of small children living in homes with private wells, as the US EPA estimates that there is a 0.042 μg/dL increase in blood Pb per 1 μg/L increase in water Pb.[11,65,66] More widespread testing and remediation of Pb in private wells are needed. Targeted sampling can be achieved by prioritizing older homes in areas with corrosive water.

Implications for Policy & Practice

- Approximately half of the homes with domestic wells sampled had measurable WLLs, and 3.3% had levels that exceeded the 15-ppb level that applies to community water systems.

- Homes built before 1987 were more likely to have measurable Pb and far more likely to have Pb levels of 2 ppb or more than homes built since 1986.

- Homes built in or before 1986 that had corrosive groundwater were 11 times more likely than newer homes with noncorrosive water to have detectable water Pb.

- A screening strategy was developed, containing 2 questions: (1) Was the home built before 1987? or (2) Is well water relatively corrosive?

- This approach was 88% sensitive and 42% specific for identifying homes with measurable Pb in well water.

- LHDs in areas of corrosive ground water should promote targeted testing of WLLs, particularly among homes built before 1987.

- The finding that the highest WLLs were nearly all particulate Pb, and that on retesting months later, the highest levels had decreased significantly, suggests episodic release of particulate Pb. In addition to effective mitigation, water sampling strategies need to be developed to account for this.

- Policies to protect rural residents—particularly households with pregnant women or small children—from water Pb are needed, as is financial support for testing and remediation.

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