Using the Lead and Copper Rule Revisions Five-Sample Approach to Identify Schools with Increased Lead in Drinking Water Risks

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Cite This: https://doi.org/10.1021/acs.estlett.1c00845

ABSTRACT: Despite public concern, the risk of lead exposure from schools remains poorly understood. The Lead and Copper Rule Revisions (LCRR) include, for the first time, a five-sample lead testing requirement for all elementary schools. However, the United States Environmental Protection Agency does not define school-wide lead risk or provide clear guidance on how results should be interpreted. Using the Massachusetts Lead in School Drinking Water Database, we explored the application of the LCRR sampling approach and provide insight into the magnitude and distribution of lead in water in Massachusetts public schools. We observed that 12% of fixtures had first draw lead >15 ppb and 3% after a 30 s flushing. Approximately 90% of fixtures with lead >15 ppb were clustered in 34% of schools. We determined a school-wide 90th percentile of 10 ppb closely approximated this clustering of problem fixtures and were able to identify schools with problem fixtures using the five-sample approach with a confidence >90%. Fixtures releasing lead >1 ppb occurred in >90% of schools and represented 58% of first draws and 33% of 30-s flushed samples. Overall, our study provides an approach to classify a school’s lead risk, which could help water utilities and schools prioritizing testing and remediation efforts.

INTRODUCTION

The Flint Water Crisis has spurred an era of heightened awareness about lead in drinking water, especially for young children.1,2 The widespread occurrence of lead in school drinking water is well-established3–11 and consumption of school water has been estimated to increase blood lead levels.3,12 Outlined in the Lead and Copper Rule Revisions (LCRR) are sampling requirements for daycares and elementary schools constructed before 2014.13 The United States Environmental Protection Agency (USEPA) requires that schools collect samples from “two drinking water fountains, one kitchen faucet used for food or drink preparation, one classroom faucet or other outlet used for drinking, and one nurse’s office faucet, as available”.13 The effective date of the LCRR has been delayed until December 16, 2021, to allow the USEPA to conduct a thorough review of regulatory changes and their necessity.14,15 Monitoring and maintaining water quality in buildings can be challenging due to a large quantity of fixtures, complex plumbing networks, and fluctuating water use patterns.3,6,15 There are concerns that the LCRR school sampling approach may fail to identify high-risk fixtures and schools, and undermine comprehensive voluntary sampling efforts.3,16 While some argue that extrapolating sample results assumes concentrations are uniform within buildings,3,17 others suggest that sample size should be a function of data variability and desired accuracy.18 Using school lead in water sampling data from Massachusetts, we explored the LCRR sampling approach by (a) characterizing the occurrence and magnitude of lead in school drinking water, (b) evaluating lead variability across fixtures and within schools, and (c) examining the ability of the five-sample testing approach to identify schools with fixtures releasing >15 ppb lead.

MATERIALS AND METHODS

School Databases. The Massachusetts Department of Environmental Protection (MassDEP) maintains a database of lead and copper results for schools and childcare facilities.19 As there were limited data collected for childcare facilities or other school types, we focused exclusively on public schools. Additional information about the MassDEP program is provided in Supporting Information, Section SI-1. Between 2016 and 2020, 47 727 first draw 250 mL samples were collected after 8–18 h of stagnation along with 36 639 corresponding 30-s flushed 250 mL samples (Table SI-1). Sampling included 1094 schools from 184 multischool districts, accounting for 59% of schools and 62% of districts.

Received: October 18, 2021
Revised: November 22, 2021
Accepted: November 24, 2021
During the first year of the program, 65% of samples were collected and 73% of schools participated. The number of fixtures sampled per school ranged from 1 to 280 (median of 35; Figure SI-1). Fixture type was recorded for 67% of samples in 738 schools (Table SI-2). The Massachusetts Department of Elementary and Secondary Education database of student enrollment and indicator characteristics were used to determine if lead occurrence varied based on demographics.

Characterization of Lead in School Water. Studies have used several thresholds to characterize elevated lead levels at fixtures and within schools (Section SI-2). In our study, we used a fixture threshold of 15 ppb, which is the MassDEP school fixture shutoff threshold. We observed a clustering of fixtures >15 ppb in schools that had a school-wide 90th percentile (P90) > 10 ppb (Section SI-3). Specifically, 89.8% of fixtures >15 ppb were located in schools that had a P90 > 10 ppb. Therefore, we classified schools as low- or high-P90 based on this 10 ppb delineation.

We compared the demographic characteristics of schools that participated (n = 1070) and did not participate in testing (n = 777) to determine representation of schools in the MassDEP database. Because of code discrepancies, 24 participating schools could not be paired with demographic data and were therefore not included. Participating schools tended to be larger (i.e., more students, more classes, and larger class sizes) and have a lower percentage of African American, Native Hawaiian, and Pacific Islander students (Table SI-3). There was no correlation between school characteristics and number of samples collected (Table SI-4). We performed statistical analysis using R version 3.6.0. We used Spearman’s correlation to examine the relationships between school demographic characteristics and lead results, and to understand relationships between different measures of lead risk (e.g., school-wide median vs percentage of samples >15 ppb). We used the Wilcoxon test to evaluate differences between schools that did and did not participate in testing, the number of samples per schools, and fixture types. We calculated the coefficient of variation (CV; i.e., standard deviation/mean) to examine lead variability within schools, across fixture types, and between low- and high-P90 schools.

Creating LCRR Sampling Events. To simulate theoretical LCRR sampling events, we used a bootstrapping approach to resample schools that had >50 first draws samples (n = 396; Section SI-4). For each school, five samples were selected randomly without replacement (i.e., each sample could only be selected once within a simulation), and this process was repeated 500 times. A total of 197 500 five-sample simulations were generated. We also simulated LCRR-specified sampling events (i.e., selected two drinking water fountains, 1 kitchen faucet, 1 classroom faucet or other outlet used for drinking, and one nurse’s office faucet) using the 235 schools with >50 first draw samples and fixture type record. We compared the
resulting median P90 between the two approaches (Section SI-5) and found no significant difference in reporting. Therefore, we included all 396 schools and used a random sampling of fixtures in our bootstrapping analysis.

We used the five-sample results as a screening method to determine if schools were at low or increased risk of being a high-P90 school. We used two methods to interpret the five-sample results: (1) the number of samples >5 ppb and (2) the five-sample P90 (i.e., average of two highest samples). We selected the number of samples >5 ppb because some state laboratories have a detection limit of 5 ppb.23 We selected the five-sample P90 because utilities serving <100 people are only required to collect five samples and calculate the P90 as the average of the two highest concentrations for their LCR system-wide sampling.23 We classified schools as low or increased risk of being a high-P90 school using these approaches and then compared results with the true P90 from schools. We calculated the accuracy (number of simulations correctly classified as low and increased risk divided by the total number of simulations), false negative rate (number of simulations incorrectly classified as low risk divided by the total number of true P90 > 10 ppb simulations), and false positive rate (number of simulations incorrectly classified as increased risk divided by the total number of true P90 < 10 ppb simulations).

# RESULTS AND DISCUSSION

## Occurrence of Lead in School Water Was Widespread

More than 1 in 10 first draw samples (12.1%) exceeded 15 ppb, with concentrations as high as 42 000 ppb (Figure SI-2). Most lead problems were associated with the fixture and immediately adjacent plumbing as only 2.7% of 30-s flushed samples were >15 ppb. Approximately two-thirds of schools (63.6%) had one or more fixtures with first draw lead >15 ppb, and half (50.3%) had two or more fixtures. This is consistent with prior work documenting widespread occurrence of first draws >15 ppb.3,8,9 When considering a 1 ppb threshold, 58.0% of first draws and 32.6% of 30-s flushed samples were >1 ppb. More than 93% of schools had two or more fixtures with first draw >1 ppb, suggesting sources throughout the building plumbing were releasing trace-level lead. These results are not surprising as many schools were constructed using lead-bearing plumbing materials (e.g., leaded solder, brasses), and even new “lead-free” plumbing components can still release trace-level lead.35,26

The median school-wide CV value in first draw samples was 1.5 (Figure SI-3). Previous studies reported CV values of 0.5—1.2 when doing repeat testing at individual fixtures and 0.3—1.9 when conducting sampling in water utilities across multiple sites.4,18 The elevated variability observed in this study may reflect both the range of fixture types sampled and the complexity of internal plumbing in buildings. While these factors pose unique challenges for assessing school-wide lead risk, school-wide CV values were positively correlated to both the percentage of samples >15 ppb in schools and school-wide P90 values, indicating a link between variability and overall lead risk (Figures SI-4 and SI-5).

Water fountains had a lower median first draw lead compared to other fixtures (Wilcoxon Test, p < 0.001; < 0.5 vs 2.3 ppb) and lower fraction of first draws >15 ppb (p < 0.001; 8.5% vs 14.6%; Table S2, Figures 1A and SI-6). These trends are in keeping with prior studies documenting differences in lead levels based on fixture type.3,8 At schools where fixture type was labeled (n = 738 schools), the school-wide median first draw CVs were lower among water fountains (CV = 0.9) than other fixtures (CV = 1.3; p < 0.001; Figure SI-7). Overall, water fountains comprised more than 40% of all fixtures sampled yet were responsible for 13.4% of first draws >1000 ppb (n = 15 of 112; Figure SI-8; Table SI-5).

Differences in lead exposure have been documented based on demographics, with low-income and minority homes having higher rates of elevated blood lead levels, lower quality water, and higher prevalence of lead infrastructure.27,28,29 We observed that lead levels did not vary based on school demographics. While the average number of students in a class was statistically different between low- and high-P90 schools, this difference was only 0.3 students (Table SI-6). There was no correlation between school demographic characteristic and the number of first draws >15 ppb per school and school-wide first draw P90 (Table SI-7).

## Fixtures with First Draws >15 ppb Were Clustered.

We observed that 90.0% of fixtures with first draw lead >15 ppb were located in 376 schools (34.4%; Figure 1B). We explored strategies to best approximate this clustering (Section SI-3) and determined that a school-wide P90 of 10 ppb was optimal. In brief, we observed a strong correlation (r = 0.89; Figure 1C) between the number of samples >15 ppb within a school and the school-wide P90, suggesting that P90 was a strong indicator of this clustering. We selected a P90 of 10 ppb, as 89.9% of fixtures >15 ppb were located in 39.9% of schools. A P90 threshold of 15 ppb only captured 82.2% of fixtures >15 ppb, and a P90 threshold of 5 ppb identified 58.7% schools.

We observed that low-P90 schools (i.e., school-wide P90 < 10 ppb) had a median first draw lead of <1 ppb and median P90 of 3.3 ppb, with 2.1% of samples >15 ppb (Figure 1D). High-P90 schools had a median first draw of 4.5 ppb and median P90 of 22.1 ppb, with 24.0% of samples >15 ppb. While first draw lead levels >1000 ppb were present in both groups, these concentrations were 13 times more common in high-P90 schools—0.55% of samples in high-P90 and 0.04% in low-P90 schools (Table SI-5). Even 30-s flushed samples in high-P90 schools had higher median lead than first draw in low-P90 schools (<1 vs 1.1 ppb; p < 0.05; Figure 2D). High-P90 schools also had slightly larger variability, with a median first draw CV of 1.8 compared to 1.2 for low-P90 schools (Figure SI-9).

## Five-Sample Approach Accurately Identified High-P90 Schools.

As USEPA does not provide guidance for the interpretation of five-sample testing results, we evaluated three approaches: (1) number of samples >5 ppb, (2) the five-sample P90, and (3) combination of these two approaches. We used these approaches as a screening method to determine if the five-sample results were generated at a school that was low or increased risk of being a high-P90 school. We grouped the five-sample results based on the number of samples >5 ppb or natural breaks in the five-sample P90 results (i.e., a P90 < 4 ppb and P90 > 10 ppb) to understand the likelihood that a given five-sample result originated from a high-P90 school (Figure 2).

Among the number >5 ppb simulations, the most common result was 0 samples >5 ppb (42.3% of simulations; n = 83 524; Figure 2A, Table S8), and 90.8% of these results were from low-P90 schools. When three or more samples were >5 ppb (21.6%; n = 42 615), 94.6% of results were from high-P90 schools. We defined five-sample results where 0 samples >5 ppb as indicating a low risk and three or more samples >5 ppb
indicating an increased risk of originating from a high-P90 school. We found that 63.9% of our simulations could be classified as low or increased risk, with a 92.1% accuracy. Our false negative rate was 16.0%, and the false positive rate was 2.9% (Table S9). However, when only one or two samples were >5 ppb (36.1%; n = 71361), these results could not be confidently attributed to either group (50.2% were from high-P90).

For the five-sample P90 simulations, results were grouped based on natural breaks in our simulations (i.e., <4 ppb and >10 ppb). Results <4 ppb occurred in 43.9% of simulations, and 90.5% of these results were from low-P90 schools (Table S10). When the P90 was >10 ppb (34.3%; n = 67785), 83.9% of results were from high-P90 schools. Even with a P90 > 40 ppb, the likelihood of identifying high-P90 schools was still <90%. We defined five-sample results with a P90 < 4 ppb as indicating a low risk and P90 > 10 ppb indicating an increased risk of originating from a high-P90 school. Using this classification, 78.2% of simulations were classified as low or increased risk, with an 87.6% accuracy. Our false negative and false positive rates were similar (12.6% and 12.2%, respectively; Table S11). P90 results between 4 and 10 ppb occurred in 21.7% of simulations and could not be confidently attributed to either group (44.1% were from high-P90).

We explored combining these two methods to improve classification performance (Figure 2C). Since the number of samples >5 ppb had a higher accuracy rate, we classified results based on number of samples >5 ppb and then classified based on the P90 value (Table S12). This approach provided additional insight into the lead occurrence (Table S13) and the likelihood of being an increased risk school (Table S14). For example, we improved our confidence of identifying low risk schools (0 samples >5 ppb), as there was only a 3.5% likelihood of a high-P90 school being misclassified when P90 was <1 ppb but 29.1% when P90 was 4−5 ppb. For 1−2 samples >5 ppb, we observed that when P90 > 5 ppb there was at least a 39.1% likelihood that the school was an increased risk school. Overall, we found that combining our two approaches improved our ability identifying a school’s risk level.

**LCRR Sampling Approach Could Help Water Utilities Prioritize Testing and Remediation Efforts.** The intention of the LCRR five-sample approach is to “serve as a preliminary screen for lead risk” and “inform whether action is needed,” but the USEPA does not define school-wide lead risk or provide clear guidance on how results should be interpreted.30 This is in contrast to the interpretation guidance provided for the system-wide sample results (i.e., a P90 > 10 ppb triggers additional testing, and >15 ppb requires corrective action).30 We provide an approach to classify a school’s lead risk based on the distribution of reported lead levels in Massachusetts schools, and we accurately (>90% confidence) classified schools as low or increased risk using the five-sample results. However, our approach could not classify risk based on a 1 ppb threshold. As 58% of first draw samples were >1 ppb and were reported in >90% of schools, almost all schools would be identified as increased risk. Our findings support the idea that initial efforts should prioritize schools where fixtures >15 ppb are concentrated, characterized by high P90 lead values. Later efforts in lower risk schools should address lead contributions from “lead-free” plumbing and implement remediation strategies to reduce lead levels to <1 ppb.

**More attention should be given to childcare facilities, as childcare facilities were poorly represented in the Massachusetts database and in the literature.**14,15,17 While larger childcare facilities might show similar patterns of clustering and lead contamination as schools, such trends may not be consistent with home daycares and childcare facilities in smaller buildings.13,17 Smaller childcare facilities are likely to have simpler internal plumbing with more continuous water use and
are served by smaller diameter service lines which could be lead pipes. Although prior work has shown that consumption of water from most fixtures in schools and childcare facilities will not impact children’s blood lead levels, there are some instances of very high lead levels. This is particularly concerning for childcare facilities, as infants consuming reconstituted formula are at highest risk of lead in water exposure, as water may be >85% of their total lead exposure, further underscoring the importance of childcare facilities. There is a critical need to understand the magnitude and extent of lead in drinking water at childcare facilities and if and how this would be characterized using the LCRR two-sample testing approach. Lead testing of drinking water in schools and childcare facilities is currently voluntary at the federal level, but some states have mandatory testing requirements. The 1988 Lead Contamination Control Act encouraged testing in schools and childcare facilities and remediating fixtures that release elevated lead levels. In 2006, the USEPA launched the “3Ts for Reducing Lead in Drinking Water in Schools” program which established a 20 ppb in a 250 mL sample lead threshold for schools. However, this threshold was replaced in 2018 with the phrasing “to the lowest possible concentrations”. As a result of having no uniform national approach, studies use both 15 and 20 ppb thresholds and various sampling approaches. This has rendered comparisons across schools and states challenging, but up to 58% of first draw school water samples exceed targeted thresholds. The USEPA has a small funding program established under the Water Infrastructure Improvements for the Nation (WIN) Act of 2016 to provide funding for lead in school water testing, but this program does not provide support for replacement of plumbing fixtures. Financial constraints are a primary barrier preventing policy implementation in schools. While school administrators acknowledge the importance of drinking water, there are other pressing concerns that may have higher priority (e.g., academic demands). Moreover, this is a significant new regulatory requirement for water utilities (e.g., for developing an inventory of these facilities, arranging sampling logistics, reporting results back to the facilities). As there are water utilities currently struggling to satisfy USEPA Safe Drinking Water Act requirements, to ensure implementation of this new lead testing platform, additional resources and technical assistance are likely needed.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.estlett.1c00845.

Five sections, nine figures, and 14 tables provide more information about MassDEP sampling; clustering of fixtures >15 ppb lead; our bootstrap analysis; lead results for school based on groupings; and lead results for five-sample simulations (PDF)

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This research was supported by the USEPA “Untapping the Crowd: Consumer Detection and Control of Lead in Drinking Water” (No. 8399375) and Northeastern University. The authors would like to thank the Massachusetts Department of Environmental Protection and Massachusetts Department of Elementary and Secondary Education for providing guidance and feedback on their databases.

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