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Lessons from the first year of compliance sampling under Michigan's revised Lead and Copper Rule and national Lead and Copper Rule implications

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Abstract

In 2018, Michigan revised its Lead and Copper Rule (LCR) compliance sampling requirements to better represent the potential lead contribution from lead service lines (LSLs). The first year of sampling results under the new requirements were analyzed to determine their impact on lead sampling results. The dataset reveals statistically significant higher detected lead levels, both at individual sample sites and in some water system 90th percentiles. Michigan's LCR results reveal the percentage of public water systems with LSLs exceeding the lead action level (15 ppb) increasing to 13% compared to 2% under the previous sampling protocol. Michigan's experience demonstrates that solely collecting first-liter data, consistent with current LCR requirements, is inadequate for detecting the higher range of lead concentrations commonly found in LSL samples. As the 2021 EPA LCR revision includes fifth-liter and removes first-liter compliance sampling, Michigan's lessons portend national implications. This paper evaluates Michigan's novel 2019 LCR results, compares the results to previous sampling periods, and shares lessons learned for timely national policy decisions.

KEYWORDS

compliance sampling, Lead and Copper Rule, lead service line, water quality data

1 | INTRODUCTION

In response to the Flint water crisis, the Michigan Department of Environment, Great Lakes, and Energy (EGLE), formerly known as Michigan Department of Environmental Quality (MDEQ), revised the Michigan Lead and Copper Rule (LCR) in 2018 (MDEQ, 2018; 2018 MR 11). Prior to this revision, Michigan, like most states, had adopted and implemented the federal Environmental Protection Agency's (EPA's) 1991 LCR (EPA, 1991a, 40 C.F.R. §141.80–141.91) with updates to maintain consistency with EPA's minor revisions (EPA, n.d.).

The currently implemented federal LCR is a treatment technique rule designed to reduce the corrosion of service lines and plumbing materials that release lead and copper into the drinking water in community water systems and nontransient noncommunity water systems. It establishes requirements for water sampling, action levels for lead and copper, and steps that must be taken when the 90th percentile of sampling results exceeds lead or copper action levels.

For LCR compliance sampling, public water systems (PWSs) collect the first liter of water out of a cold-water kitchen or bathroom faucet after a minimum of 6 h with no water use in the home. For large PWSs (>100,000 customers), 100 compliance samples must be collected; however, most large PWSs meet requirements for reduced monitoring and collect only 50 compliance samples (EPA Office of Water, 2019). Systems that meet reduced monitoring criteria also reduce their sampling frequency from every 6 months to annually or every 3 years. Water systems with lead service lines (LSLs) are instructed to collect half of their samples from sites with LSLs and the other half from homes with copper pipes joined with lead-containing solder in premise plumbing installed after 1982 (EPA, 1991b, 40 CFR § 141.86 (a)(8)).

As prescribed by the LCR, the compliance sample results are used to calculate the 90th percentile lead value for the entire water system. The 90th percentile is compared to the 15 ppb action level to determine if additional actions are required. The action level of 15 ppb is an indicator of corrosion control effectiveness. Although often misinterpreted as a health-based standard, it is not a measure of public health protection. The nonenforceable EPA Maximum Contaminant Level Goal (MCLG) establishes 0 ppb as the safe level of lead in water (EPA, 1991a, 40 C.F.R. §141.80–141.91).

The federal LCR does not require the identification and removal of LSLs when the 90th percentile of lead results is below the lead action level, nor sampling procedures that attempt to measure the lead contribution from LSLs. If an LSL is present, it is the greatest contributor of lead in drinking water (Lytle et al., 2019; Sandvig et al., 2008; Tully et al., 2019). The LCR's mandatory first-liter sample rarely includes water that was in contact with an LSL during the 6-h stagnation period (see Figure 1). The first-liter sample measures the lead-in-water contribution from lead in premise plumbing (fixtures, solder, valves, etc.), accumulated lead from the LSLs, and lead particulate captured in the aerator that can originate from anywhere in the plumbing system.

Studies involving sequential sampling in homes with LSLs have found lead content is frequently higher in later samples compared to first-liter samples (Chicago Department of Water Management, n.d.; Del Toral et al., 2013; Lytle et al., 2019). For example, sequential data from Flint, Michigan, indicated the 3rd- to 4th-liter samples were highest, and sequential data collected in Chicago revealed the 6th to 8th liter were often highest (Batterman & Olson, 2018; Kaplan, 2017; Rosenthal & Craft, 2020).

Because the current federal LCR does not require regulated water systems to collect sequential water samples or samples of water that have been in contact with LSLs, there is no standardized national database of LSL data in a variety of water quality conditions. Only first-liter LCR

Article Impact Statement
LCR sampling needs updates: 1st L lead samples from mixed sampling pools miss LSL contribution; 5th L captures more elevated lead.

compliance sampling data are available in states' standardized compliance databases. Therefore, most of the LSL, or sequential, sampling data that have been widely studied come from either individual researched water systems (e.g., Cincinnati (Tully et al., 2019), Milwaukee (Lewis et al., 2017)) or samples collected in response to a crisis, such as in Flint, MI (FlintWaterStudy, 2015; Masten, n.d.; Pieper et al., 2018); Newark, NJ; Washington, DC; and Pittsburgh, PA. Lead occurrence data reviews have focused on available first-liter data compiled from federal LCR compliance sampling (Brown et al., 2013; Grant et al., 2020; Slabaugh et al., 2015).

Recognizing the limitations of the federal LCR, Michigan revised its LCR in a way that would better identify the potential range of lead in water. First, the Michigan LCR clarifies lead sampling protocols: Pre-stagnation flushing, aerator cleaning and removal, and the use of small-mouth bottles for compliance samples are no longer allowed. The Michigan LCR requires PWSs with LSLs to take ALL their LCR compliance samples from homes with LSLs and collect both first- and fifth-liter samples to better capture the lead contribution from the LSL while still capturing the lead contribution from premise plumbing .

The Michigan LCR revised the 90th percentile calculation to incorporate the new first- and fifth-liter sampling protocol. Whereas the federal LCR calculates the 90th percentile of all first-liter compliance sample results, the Michigan LCR uses the highest value for each sample site, the first- or fifth-liter sample, to calculate the 90th percentile value for the water system.

In addition to the modified sampling requirements, the revised Michigan LCR includes new requirements for (1) creating Distribution System Materials Inventories, where water systems identify the materials of all service lines, including portions on both public and private property; (2) updating sampling pools to ensure compliance sampling sites have confirmed LSLs in PWSs with LSLs; and (3) fully replacing LSLs at an average of 5% per year to be completed in 20 years. The compliance sampling results from the Michigan LCR's first year of implementation (2019) include this unique dataset of samples from LSL homes that reflect a variety of source water qualities and corrosion control treatments.

The federal LCR was recently revised in 2021 with new requirements that may become effective in 2024

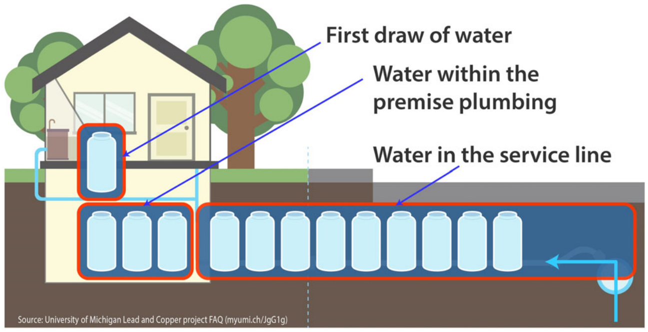

FIGURE 1 Visual representation of house water draws. Reprinted from MI revised Lead and Copper Rule (LCR) project, n.d., from the University of Michigan Graham Sustainability Institute, http://graham.umich.edu/project/revised-lead-and-copper-rule/images. Reprinted with permission

(EPA, 2021b, 86 F.R. 4198). The public comment period was re-opened from March 9, 2021, through July 31, 2021, and the effective date of the revisions was extended to December 16, 2021 (EPA, 2021a). The updated 2021 EPA LCR Revisions (LCRR), as finalized in January 2021, requires water systems with LSLs to collect all samples at homes with known LSLs and analyze only fifth-liter samples for lead, dropping the first-liter lead sample (EPA, 2021b, 86 F.R. 4198). The 2021 EPA LCRR also defines a lead trigger level of 10 ppb. When the trigger level is exceeded, water systems must initiate certain corrosion control activities. The Michigan dataset provides timely insights into the potential national implications of the compliance data collected from mandated fifth-liter samples from LSL homes, and the information lost when water systems stop analyzing first-liter samples at LSL homes. Although the public comment period has closed, lessons learned from Michigan's novel LCR experience still have potential to drive additional changes to the 2021 EPA LCRR, either before the revisions become effective or in subsequent revisions.

The purpose of this paper is to evaluate the novel 2019 Michigan LCR dataset, compare the data from the new sampling protocols to results from previous sampling periods, evaluate the magnitude of fifth-liter sample results compared to first-liter sample results, and evaluate the impact of fifth-liter samples on 90th percentile values. The implications of these results for the 2021 EPA LCRR are discussed.

2 | DATA AND METHODS

2.1 | Data description

In early 2020, EGLE publicly posted 634 90th percentile values from PWSs that collected LCR compliance samples during 2019 and shared with the research team individual sampling data from 629 PWSs (K. Philip, personal communication, January 21, 2020). Four of the 90th percentile results did not represent independent water systems because they were reported for independent service areas within water systems. Additionally, data from the Flint water system were not included in most of this paper's analyses because Flint's individual sampling data were not provided in the dataset shared with the research team (K. Philip, personal communication, January 21, 2020). Some (15.7%) of the PWSs were on a schedule collecting samples between January 1 and June 30, but the majority (84.2%) of the PWSs collected samples during the standard monitoring period between June 1 and September 30. Of note, due to reduced monitoring schedules, the 629 PWSs represent 46.0% of the 1367 independent community water systems that were expected to comply with the LCR from all water systems listed on EGLE's MI Lead Safe website in 2019 (State of Michigan, 2020).

A dataset of 1312 90th percentile values from 2016 to 2018 was used for comparison to the 2019 results (State of Michigan, 2019). In order to match PWS sampling results during the two monitoring periods, the comparison dataset included multiple years, 2016 through 2018, because of the reduced monitoring schedule.

The Michigan LCR requires only water systems with LSLs to collect both first- and fifth-liter samples at each compliance sampling site. The 2019 dataset included 134 PWSs (21%) with at least one first- and fifth-liter sample pair (hereafter referred to as LSL PWSs), and 495 PWSs (79%) that took first-liter samples only (non-LSL PWSs). This is consistent with the American Water Works Association (AWWA) estimate that about 80% of PWSs in the United States do not have any LSLs (AWWA, 2021). Of note, 50 of the 134 LSL PWSs that collected at least one first- and fifth-liter sample pair also collected at least one first-liter-only sample at different addresses, implying that the pairs were collected at LSL sites and the first-liter-only samples were collected at non-LSL sites.

When the study dataset is evaluated as a whole, there are 2932 first- and fifth-liter sample pairs from the 134 PWSs that have LSLs, and 7046 first-liter-only samples from PWSs with ($n = 753$) and without LSLs ($n = 6293$) (see Figure 2).

Lastly, the 2019 compliance sampling period occurred before Michigan PWSs were required to complete their Preliminary Distribution System Materials Inventory and sampling pool updates. As a result, some first- and fifth-liter sample pairs were collected at sites without LSLs, but these particular sample pairs could not be identified because the dataset lacked site-tiering information. While the new Michigan LCR testing protocol called for utilities with LSLs in their service area to take their samples *only* from homes with LSLs, there were instances in this

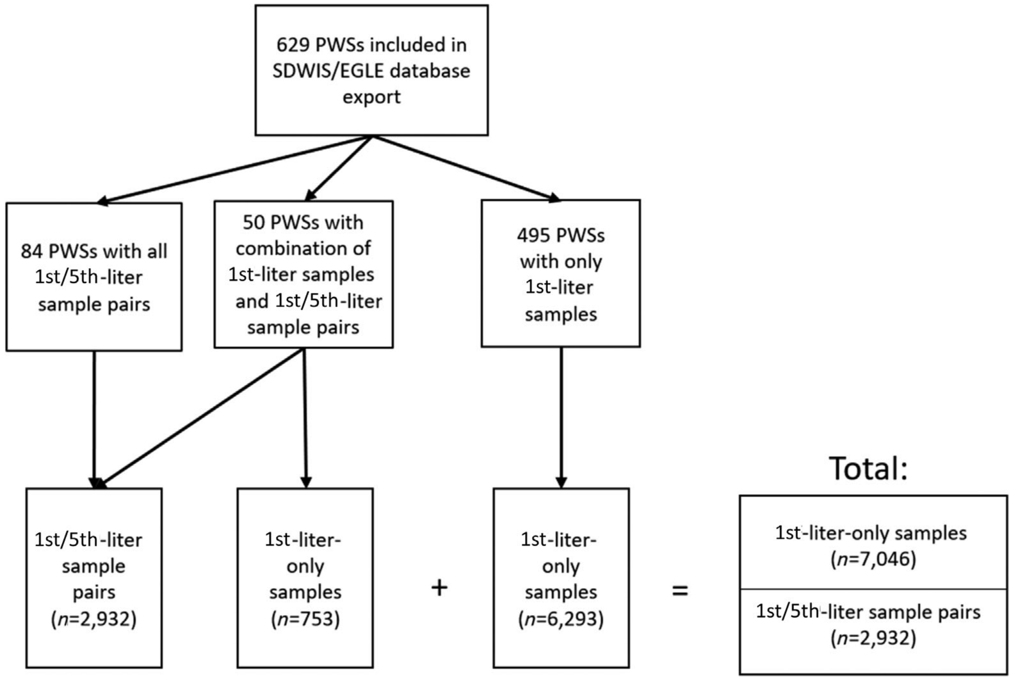

FIGURE 2 Summary of the 2019 Michigan Lead and Copper Rule compliance sampling data. EGLE, Michigan Department of Environment, Great Lakes, and Energy; PWS, public water system; SDWIS, safe drinking water information system

dataset where samples were taken and included from non-LSL locations. Evidence for this includes communities that reported first- and fifth-liter sample data but had a smaller number of confirmed LSLs in their Preliminary Distribution System Materials Inventory (Michigan Department of Environment, Great Lakes, and Energy, 2020), and communities that collected first- and fifth-liter sample pairs that later made statements that they have no LSLs (Blackman Charter Township, 2020). The incompleteness of the Distribution System Materials Inventories at the time these samples were collected may have resulted in an under-representation of LSL sampling sites.

2.2 | Analysis and methods

Data from Michigan's 2019 LCR compliance samples were downloaded, sorted, and prepared for analysis using Microsoft Excel. All lead test results were standardized to μg/L as some data were initially reported in the dataset as mg/L. Data were then grouped by systems that collected at least one fifth-liter sample paired to a first-liter sample and systems with only first-liter samples. Then, using data on the system IDs, addresses of collection sites, and collection dates, the fifth-liter results were matched to their corresponding first-liter results. The data were reported from individual PWSs that use a variety of different certified laboratories, and consequently, variable reporting limits. The file provided by EGLE includes only data reported as zeros and positive values. No information on reporting limits or detection limits was provided. Ninetieth percentiles were computed using EPA's guidance for calculating 90th percentiles under the LCR (EPA Office of Water, 2010).

Three types of analyses were completed. The first combined the lead sampling results statewide and included the comparisons of three separate values: First-liter test results, fifth-liter test results, and the highest of the two results. These analyses show how the combined statewide results would compare if only first-liter test results were collected (as was the prior protocol), versus the new protocol that includes first- and fifth-liter paired samples. To test for statistically significant differences, we used two types of tests for these analyses: a two independent samples proportion test to compare first-liter results between LSL PWSs and non-LSL PWSs and a paired proportion test to compare the first-liter and fifth-liter results from the same sites. The null hypothesis tested for this step was that the proportion of samples between two groups was equal and if the difference in proportions was statistically significant, we rejected the hypothesis. Tests were completed for the percent of sites of each type exceeding three major thresholds—5, 10 (the lead trigger level of the 2021 EPA LCRR), and 15 ppb (the lead action level). For each of these tests, a significance level of $p < .05$ was used.

Second, PWS 90th percentile values were computed and compared within the 2019 dataset, testing differences in PWS 90th percentiles generated from the first-liter vs. fifth-liter samples. Testing of statistically significant differences in the 90th percentiles of the two sample groups used a quantile regression and evaluated the sample type coefficient's significance.

Third, the proportions of PWS 90th percentile values exceeding the major thresholds were compared between the 2019 dataset and the dataset from the previous sampling protocol from 2016 to 2018. The statistical test used in this analysis was again a two independent samples proportion test, comparing the 2019 results to prior years.

3 | RESULTS AND DISCUSSION

3.1 | 2019 Michigan LCR comprehensive sample evaluation

As shown in Table 1, of the 495 non-LSL PWSs taking first-liter-only samples, about 70% of the samples had nondetect results for lead. Of these samples, 3.1% exceeded 5 ppb and 1.4% exceeded 10 ppb. Of the 134 LSL PWSs that took first- and fifth-liter sample pairs, 11.9% of first-liter samples exceeded 5 ppb and 4.7% exceeded 10 ppb. Of the fifth-liter samples, 20.8% exceeded 5 ppb and 9.8% exceeded 10 ppb. The 90th percentile value for the first liter of LSL sample pairs (6.0 ppb) is three times greater than the 90th percentile of first-liter-only samples (2.0 ppb); and the 90th percentile is highest for the fifth-liter samples at 10 ppb. Boxplots showing the interquartile range, median, mean, and 90th percentiles of these three groups of samples are included in Figure 3. The difference in the aggregate 90th percentile results between the first-liter LSL sample pairs and first-liter-only samples shown in Figure 3 is statistically significant at the $p < .05$ level, as is the difference between the 90th percentile of the first-liter and fifth-liter results from the LSL PWSs sample pairs.

Figure 4 shows the percent of first-liter-only, first liter of sample pairs, and fifth-liter sample results exceeding the lead MCLG, 5 ppb, the lead trigger level, and the lead action level of the 2021 EPA LCRR. When testing for statistical significance in the differences between the proportion of samples exceeding key benchmarks from the first-liter-only samples taken by non-LSL PWSs ($n = 7046$) and the first-liter samples taken by the LSL PWSs in the first liter of the sample pairs ($n = 2932$), the differences shown in Figure 4 are all significant at the $p < .05$ level. When assessing the differences in the proportion of first-liter samples from the LSL PWSs sample pairs ($n = 2932$) with the fifth-liter samples taken from the LSL PWSs sample pairs ($n = 2932$), we find the differences in proportions exceeding the 5, 10, and 15 ppb thresholds are statistically significant, but that the difference in the proportion of samples exceeding the 0 ppb threshold between first- and fifth-liter results are not.

Figure 5 shows that even though fifth-liter samples drive up the 90th percentile results, six of the lead action level exceedances (33.3%) were the result of first-liter samples alone, indicating that first-liter sample data are still important for characterizing lead risk. Water collected in first-liter samples can include lead from multiple plumbing sources. This includes lead from faucets, valves, and solder. It can also include lead particulate that may have been released from the service line or other leaded plumbing, trapped in the faucet aerator, and then rereleased when water flow was initiated for sample collection. Even when LSLs are removed under the Michigan LCR and under the proposed national infrastructure plan, it is likely that some of these smaller-magnitude lead sources will remain in homes. In addition to the fifth-liter data, continuing to collect first-liter data to characterize lead release and corrosion control effectiveness in the household plumbing remains important.

To further demonstrate the impact of adding the fifth-liter samples, Figure 6 shows the overall percentage of LSL PWSs with 90th percentiles exceeding relevant lead benchmarks based on first-liter-only and highest of first- and fifth-liter calculations. The percentage of PWS 90th percentiles exceeding each of these benchmarks is substantially higher when the fifth liter is included. The difference between the percentage of the LSL PWS 90th percentiles based on the first-liter-only results and the highest of the first and fifth liter exceeding each of the three major thresholds is statistically significant at the $p < .05$ level. This further illustrates the inadequacy of first-liter samples for representing the range of potential lead release from LSLs, and this pattern is consistent across all lead benchmarks, not just those greater than 15 ppb.

To explore the extent to which LSL contributions are captured in first-liter samples, first-liter 90th percentiles were calculated for the 84 water systems that took only first- and fifth-liter sample pairs (LSL-only PWSs) and were compared to first-liter 90th percentiles for water systems that took only first-liter samples (non-LSL PWSs). While recognizing other factors may be at play, in a sampling pool of mostly LSLs, the lead contribution from the LSL is observed in the first liter when these 90th percentiles are compared to 90th percentiles of non-LSL PWSs. As shown in Figure 7, first-liter samples from LSL-only PWSs exceeded the benchmark of 5 ppb in 37% of the water systems, compared to only 11% of first-liter samples from non-LSL PWSs, the difference of which is statistically significant at the $p < .05$ level. Although the percentages of LSL-only PWSs exceeding benchmarks of 10 and 15 ppb were twice that of non-LSL PWSs, these differences are not statistically significant.

Looking at all first- and fifth-liter sample pairs, the results reveal that for very high lead levels (>100 ppb), there are nearly the same number of results in both the first and fifth liters, 13 and 10 (0.4% and 0.3%)

TABLE 1 2019 Michigan Lead and Copper Rule compliance sample results

	1st-liter-only systems	1st-liter-only samples at LSL systems	Total 1st-liter-only samples	1st-liter samples of LSL pairs	5th-liter samples of LSL pairs
Systems	495	50	545	134	134
Samples	6293	753	7046	2932	2932
Nondetect results, *N* (%)	4427 (70.3%)	580 (77.0%)	5007 (71.1%)	1487 (50.7%)	1437 (49.0%)
$0 < x \leq 5$ ppb, *N* (%)	1663 (26.4%)	155 (20.6%)	1818 (25.8%)	1096 (37.4%)	886 (30.2%)
$5 < x \leq 10$ ppb, *N* (%)	115 (1.8%)	9 (1.2%)	124 (1.8%)	212 (7.2%)	322 (11.0%)
$10 < x \leq 15$ ppb, *N* (%)	31 (0.5%)	1 (0.1%)	32 (0.5%)	55 (1.9%)	130 (4.4%)
$x > 15$ ppb, *N* (%)	57 (0.9%)	8 (1.1%)	65 (0.9%)	82 (2.8%)	157 (5.4%)
Mean result (ppb)	1.6	1.0	1.5	3.7	4.7
90th percentile (ppb)	2.0	1.8	2.0	6.0	10.0
Range (ppb)	0.0–1139.0	0.0–140.0	0.0–1139.0	0.0–990.0	0.0–1100.0

Note: The data were reported from individual PWSs that use a variety of different certified laboratories, and consequently, variable reporting limits. The file provided by EGLE includes only data reported as zeros and positive values. No information on reporting limits or detection limits was provided. Ninetieth percentiles were computed using EPA's guidance for calculating 90th percentiles under the LCR (EPA Office of Water, 2010).
Abbreviation: LSL, lead service line.

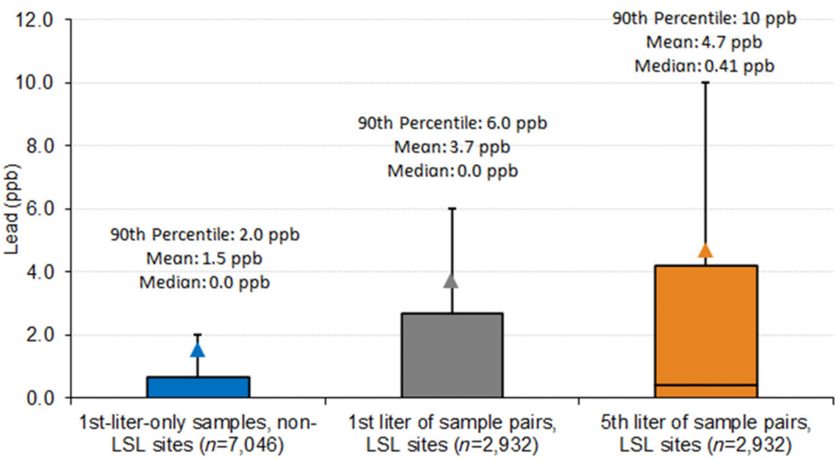

FIGURE 3 Mean and 90th percentile values of first- and fifth-liter LCR compliance samples collected in Michigan in 2019. Mean value is shown as the marked triangle data point, while 90th percentile is shown as the upper whisker bound. Maximum values are not in the presented range. LCR, Lead and Copper Rule; LSL, lead service line

respectively, a difference in the proportion of test results that is not statistically significant at the $p < .05$ level. Although these very high sample results, several greater than 1000 ppb, account for only 0.8% of the total sample results, these high-magnitude samples are concerning from both an exposure dose standpoint as well as implications for population-level prevalence, demonstrating corrosion control treatment may need to be re-optimized. These samples likely indicate the presence of particulate lead and are consistent with other research findings that particulate lead release is sporadic and unpredictable (Clark et al., 2014; Del Toral et al., 2013; Kaplan, 2017). This reiterates that although particulate lead release is rarely captured through compliance sampling, it is large in magnitude, and difficult to predict when it may land in a sample bottle or a water glass. These results indicate an equal chance of high lead samples being found in the first- or fifth-liter sample.

Under the 2021 EPA LCRR, PWSs with a 90th percentile that exceeds the 10 ppb trigger level or 15 ppb action level are required to take corrosion control treatment actions to reduce lead in water. This analysis demonstrates how the fifth-liter samples will increase the number of systems required to take these steps to reduce lead release. Further, in addition to the 90th percentile values PWSs are required to publish in their annual consumer confidence report and distribute to all customers (EPA, 1998, 63 F.R. 44,512), the Michigan LCR requires PWSs to report the range of sample results detected (MDEQ, 2018; 2018 MR 11). When more customers see the higher 90th percentile and higher range of lead values reported within their community as a result of fifth-liter sample results, they may be more likely to investigate the risk of lead exposure in their own home and take steps to mitigate their exposure. Even with fifth-liter data better representing the LSL, the consumer

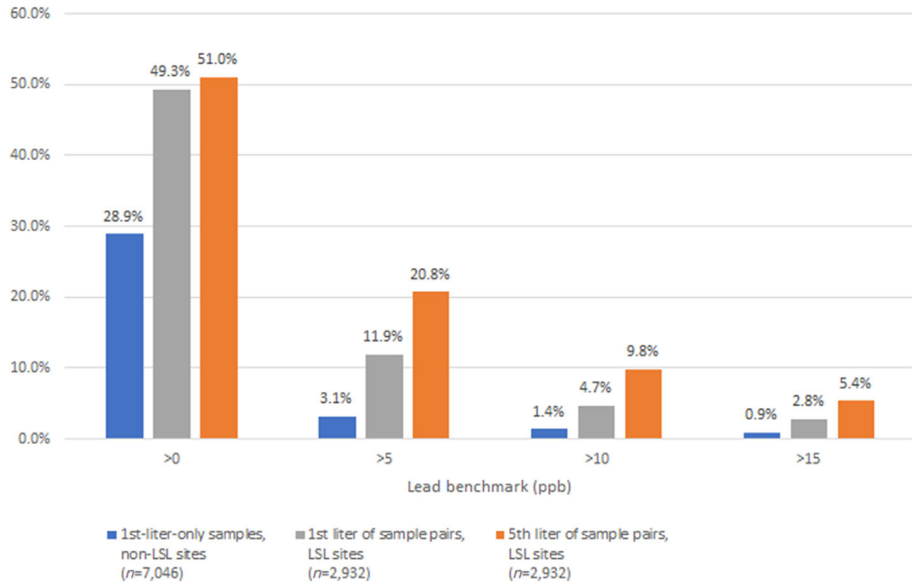

FIGURE 4 Percent of Michigan's 2019 PWS LCR compliance samples exceeding lead benchmarks by sample type. LCR, Lead and Copper Rule; LSL, lead service line; PWS, public water system

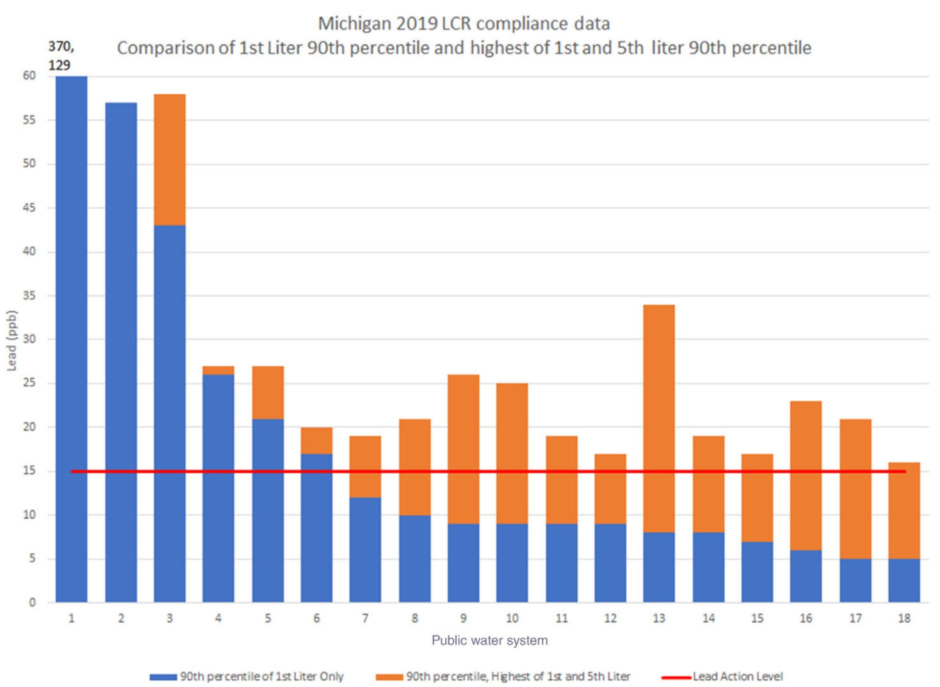

FIGURE 5 Comparison of first-liter 90th percentiles and highest of first- and fifth-liter 90th percentiles from Michigan PWSs with a 90th percentile exceeding 15 ppb in 2019. PWS, public water system

still does not know the true range of lead levels present in their home and community since the fifth liter is not guaranteed to capture the peak lead from the service line nor capture random particulate lead. The 2019 Michigan LCR dataset indicates the importance of using filters at LSL homes to reduce lead in water until the LSL can be removed. Properly maintained certified filters and bottled water provide water with lead at 5 ppb or less based on current regulations and certification requirements (NSF International, 2021; U.S. Food & Drug Administration, 2019). Informed residents may be more likely to implement these interventions for lead exposure reduction in communities with lead action level exceedances triggered by fifth-liter sampling.

3.2 | 2019 Michigan LCR comparison with previous compliance sampling period

Before comparing sampling results from previous sampling periods with the addition of fifth-liter samples at LSL sites in 2019, it is important to explore the impact of other Michigan LCR sampling protocol changes on sampling results. The Michigan LCR included the following changes in sampling protocol for the collection

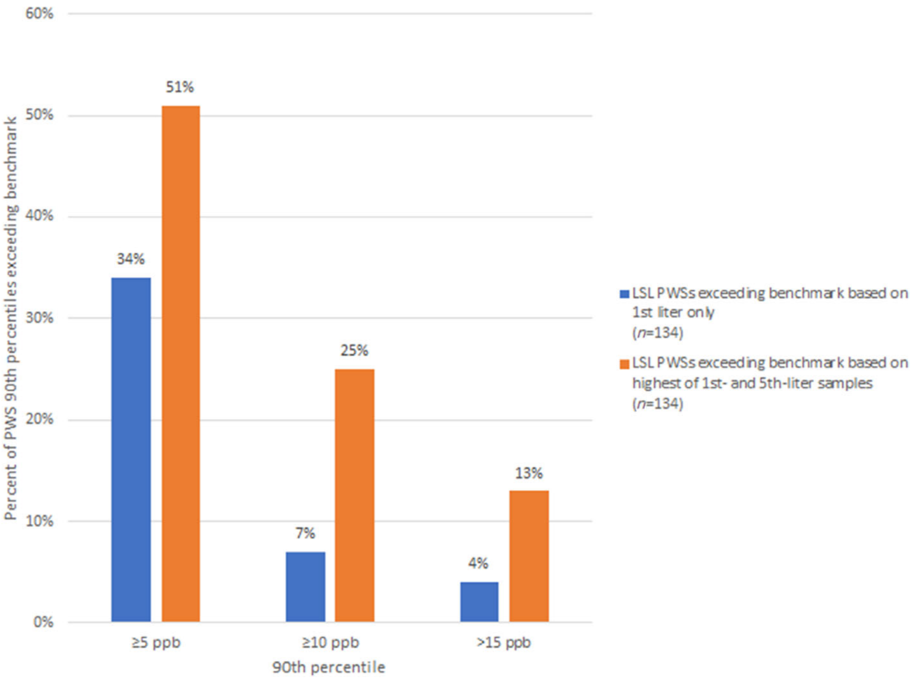

FIGURE 6 Percentage of Michigan LSL PWSs with 90th percentiles exceeding lead benchmarks in 2019. LSL, lead service line; PWS, public water system

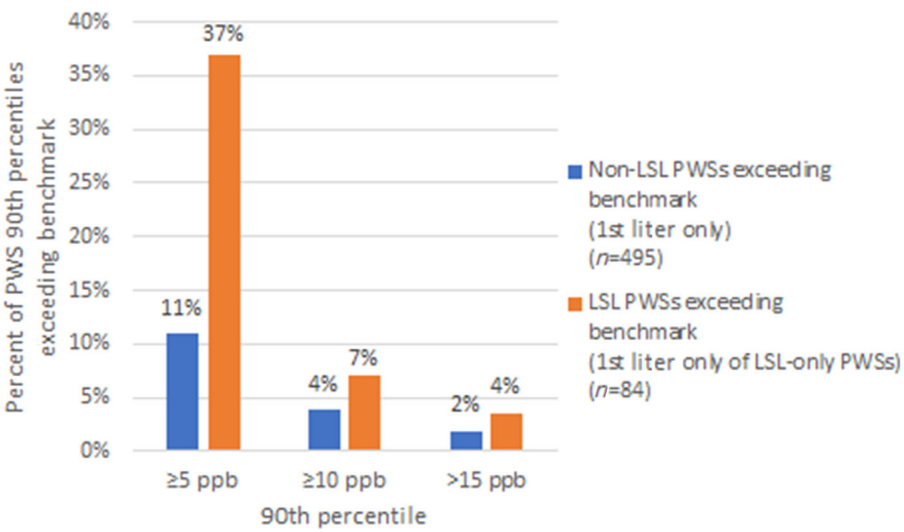

FIGURE 7 Percentage of Michigan non-LSL and LSL-only PWSs with first-liter 90th percentiles exceeding lead benchmarks in 2019. For this analysis, non-LSL PWSs were defined as those that collected only first-liter samples, while LSL-only PWSs were defined as those that collected only first- and fifth-liter sample pairs. LSL, lead service line; PWS, public water system

of first-liter samples: Mandatory use of wide-mouth bottles, no systematic flushing in anticipation of sampling, and no aerator removal or aerator cleaning. To explore the impact of changing the first-liter sampling procedures, data for PWSs without LSLs were analyzed before and after the change since there were no other sampling protocol or sampling pool changes for these water systems. For this analysis, 90th percentiles were evaluated for PWSs that took only first-liter samples in 2019 ($n = 495$). There were 69 PWSs that had a detectable 90th percentile of 1 ppb or greater in 2019, up from a previous 90th percentile of 0 ppb, and there were 69 different PWSs with a 90th percentile of 0 ppb in 2019 that previously had a 90th percentile of 1 ppb or greater. As of 2018, 65% of all PWSs had a 90th percentile greater than 0 ppb. This outcome held steady with the change in first-liter sampling protocol requirements in 2019: 64% of PWSs that collected only first-liter samples in 2019 reported a 90th percentile with detectable lead. The percentage of PWSs in each range of lead benchmarks is nearly the same for monitoring periods ending in 2018 and in 2019. This dataset reiterates that lead release in water is sporadic, with many changes in the individual PWSs detecting lead from year to year. These results may indicate that either these PWSs already updated their sampling procedures prior to the Michigan LCR revision when EPA issued sampling guidance in 2016 (Grevatt, 2016) or the changes did not result in greater detection of elevated lead concentrations.

Figure 8 demonstrates the impact of moving from the requirement for 50% LSL sampling sites under the federal LCR in the previous sampling period to a mostly LSL sampling pool at LSL PWSs under the Michigan LCR in 2019. There appears to be an increase in first-liter lead results when mostly LSL sites were sampled in 2019 in this year-to-year comparison of systems that sampled during both monitoring periods. The move to all LSL sampling sites in the Michigan LCR doubled the lead action level exceedances in LSL PWSs, not even considering the impact of the new fifth-liter samples; however, this finding was not statistically significant. Additional studies may determine whether sampling pool updates required after the 2019 compliance sampling period change this finding in future datasets. These data indicate that the change in sampling pool requirements is a likely source of the increase in LSL PWS first-liter 90th percentile values, especially when compared to the lack of an apparent increase in the first-liter sample results at non-LSL PWSs. This elevated first-liter data at LSL systems will be missed when first-liter samples are no longer analyzed for lead under the 2021 EPA LCRR.

Although the first-liter 90th percentile results are higher for systems with LSLs, indicating greater risk of lead exposure in systems with LSLs, the first-liter data still do not reflect the higher lead values detected in fifth-liter samples that also contributed to the higher percentage of lead action level exceedances in 2019. Relying on EGLE-published 90th percentile datasets, of the 1312 PWSs with a reported lead 90th percentile value for the monitoring periods ending in 2018, 14, or 1.1%, exceeded the lead action level using the former protocols for calculating 90th percentiles. For the sampling periods ending in 2018, 11 of 1188 non-LSL PWSs exceeded the lead action level of 15 ppb (1%), and 3 of 124 LSL PWSs exceeded 15 ppb (2%). In 2019, 8 of 499 non-LSL PWSs (2%) and 18 of 134 LSL PWSs exceeded 15 ppb (13%). Overall, 26 of the 634 90th percentiles reported in 2019 exceeded the lead action level (4.1%).

3.3 | Implications for compliance with the 2021 EPA LCRR

The impact of eliminating first-liter samples from sampling procedures proposed under the 2021 EPA LCRR was evaluated. While the fifth-liter samples are more likely to capture water that was stagnant in the lead portion of a customer's water service line and the Michigan test results show higher average lead levels and 90th percentile results from LSL-only sampling pools and fifth-liter samples, the preceding analyses demonstrate that first-liter samples contribute valuable information on the profile of lead exposure risks, including the ability to evaluate long-term trends within water systems.

In order to test the impact of the 2021 EPA LCRR sampling protocol requiring only fifth-liter samples versus Michigan's LCR protocol requiring both first- and fifth-liter samples and accepting the highest of those two results, data from the 84 systems that collected only first- and fifth-liter sample pairs were analyzed. The 90th percentile results and the percent of systems above each threshold were calculated for the sampling protocol of only fifth-liter samples versus the highest result of the sample pairs.

The gray bar in Figure 9 shows if an LSL PWS 90th percentile exceeded the benchmark using the highest of the first- or the fifth-liter calculation. The difference between the highest of the two and the fifth liter represents the information that will be lost when PWSs with LSLs are no longer required to collect first-liter samples under the 2021 EPA LCRR. As discussed previously, first-liter data can represent unpredictable particulate and soluble lead that is not targeted by LCR sampling (Kaplan, 2017) and we found no evidence that high lead values (>100 ppb) are more likely to be detected in the fifth liter compared to the first liter. The first- and fifth-liter data taken together are better at capturing particulate lead release and unpredictable higher lead than the first- or fifth-liter sample alone. This analysis shows that 90th percentiles using fifth-liter-only samples miss 27.3% of the >15 ppb lead action level exceedances and 16.7% of the >10 ppb exceedances, although the differences between these two sampling protocols were not statistically significant at the $p < .05$ level (Figure 9).

Additionally, to test the importance of the combined information on lead levels detected using the combination of first- and fifth-liter samples, an analysis of the 2932 paired samples from 134 systems with at least one LSL was completed. For the samples where the highest of the two results was greater than 15 ppb, only 40 of 199 samples (20.1%) had *both* the first- and fifth-liter result above the 15 ppb threshold. Further, for the 347 samples where the highest of the two results was >10 ppb, only 77 of them (22.2%) had both the first- and fifth-liter samples above that threshold. This means selecting a sampling protocol where only the first- or only the fifth-liter samples are taken is likely to miss significant lead detections. The pair of first- and fifth-liter samples are critical to catching elevated water lead levels that can come from the LSL, the household plumbing, or both.

The 2019 Michigan LCR data were used to estimate the increase in lead action level exceedances in LSL

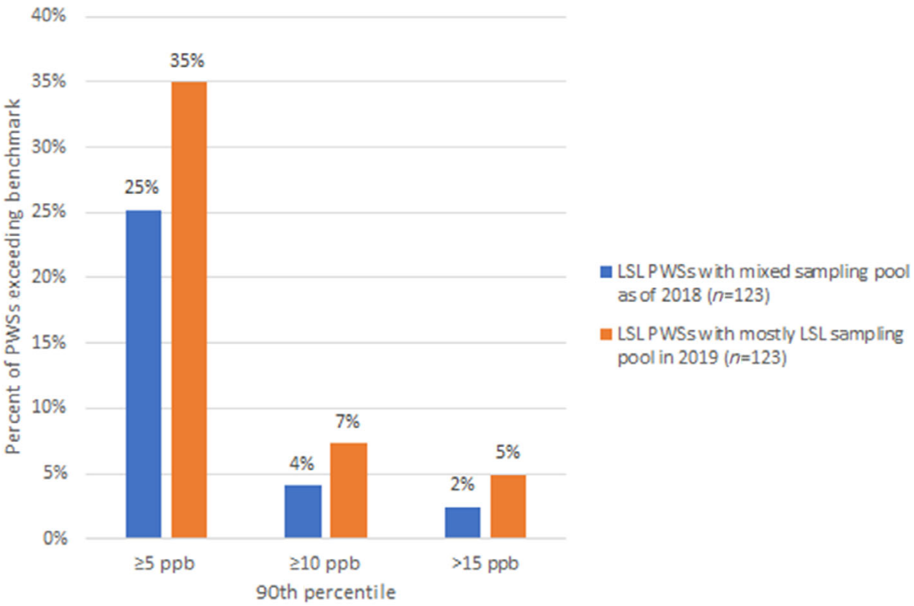

FIGURE 8 Percent of first-liter 90th percentiles exceeding lead benchmarks for PWSs that sampled both in the period ending in 2018 and in 2019, showing a switch from a mixed sampling pool to a mostly LSL sampling pool. LSL, lead service line; PWS, public water system

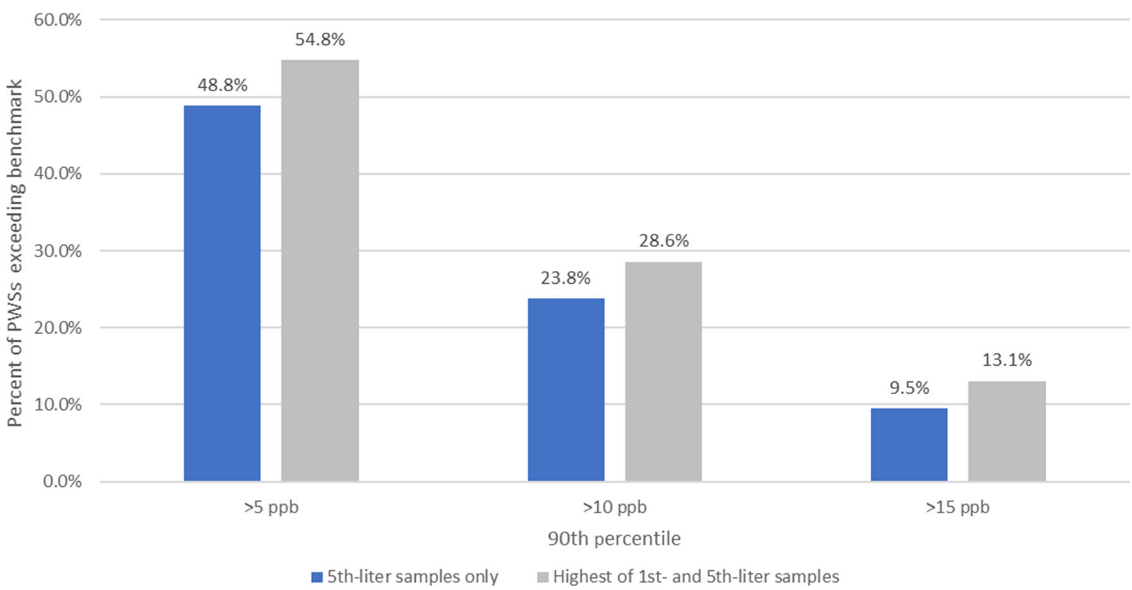

FIGURE 9 Percentage of Michigan PWSs with only paired samples in 2019 whose 90th percentiles exceeded lead benchmarks (5th liter vs. highest of 1st and 5th liter). PWS, public water system

PWSs expected under the 2021 EPA LCRR. As shown in Figure 8, 2% of LSL PWSs had lead action level exceedances under the mixed sampling pool of the federal LCR. Figure 9 shows that 9.5% of LSL PWSs had lead action level exceedances using a fifth-liter-only sampling protocol. This indicates that more than four times as many LSL PWSs are expected to exceed the lead action level under the 2021 EPA LCRR. Further, up to 13.1% of LSL PWSs may exceed the lead action level if both first- and fifth-liter samples are required under a subsequent revision.

4 | CONCLUSION

This analysis sought to evaluate Michigan's novel 2019 LCR results, compare the results to previous sampling periods, and share lessons learned for timely national policy decisions. The new compliance sampling requirements in the Michigan LCR dataset demonstrate higher lead concentrations in fifth-liter samples at LSL PWSs. The Michigan LCR results reveal the percentage of LSL PWSs exceeding the lead action level (15 ppb) increasing to 13% compared to 2% under the previous sampling protocol.

The implications of these results suggest that solely collecting first-liter data from mixed sampling pools as required by the current federal LCR is inadequate for detecting the range of lead contributed from LSLs.

Although compliance sampling is designed to identify PWSs that need to reduce lead exposure in the community, not to identify each household's exposure, the greater occurrence of lead action level exceedances with first- *and* fifth-liter sampling guarantees that more residents will receive notice and public education regarding lead in their drinking water, thus allowing them to be aware and take more proactive steps to reduce their exposure. The fifth-liter sampling data are critical for communicating the potential for lead exposure to residents of homes with LSLs. The finding of higher lead levels in both first- and fifth-liter data at LSL sample sites further supports the Michigan LCR and federal LCR requirement for PWSs to notify all customers that receive their water through an LSL, even in communities without lead action level exceedances.

The results of this analysis reinforce the need for ongoing communication and proactive primary prevention-focused interventions to minimize exposure to lead in water, including the widespread use of lead-clearing point-of-use filters until LSLs are removed. This analysis supports Michigan's requirement to remove all LSLs no later than 2041 and the federal proposal to remove the nation's LSLs.

Lastly, this analysis of Michigan's novel LCR data confers a timely opportunity to suggest a sampling strategy that could be adopted in further revisions to the 2021 EPA LCRR to better detect the potential range of lead in drinking water. This option would be to mirror the Michigan LCR:

1. Collect lead compliance samples at only *verified* LSL sites in LSL PWSs,
2. Analyze both the first- and fifth-liter samples for lead, and
3. Use the highest of the two samples to calculate the 90th percentile.

With the delay of the 2021 EPA LCRR effective date and the proposed infrastructure plan to remove all the nation's lead pipes, there has never been a more promising time to strengthen the LCR and remove the greatest burden of lead from the drinking water infrastructure. The lessons from Michigan's LCR are timely and should be used to inform revisions to the 2021 EPA LCRR that provide better lead-in-water detection and consequently better public health protection. It will be important to continue evaluating future compliance sampling datasets, especially after Michigan sampling pools were updated in January 2020 per the requirements of the Michigan LCR.

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CONFLICT OF INTEREST

Elin Betanzo and Corwin Rhyan report they have no potential conflicts of interest to declare. Mona Hanna-Attisha reports she serves as Vice Chair of the State of Michigan Child Lead Elimination Commission and as PI on the CDC Flint Registry grant.

AUTHOR CONTRIBUTIONS

Elin Betanzo: Conceptualization; data curation; formal analysis; validation; investigation; methodology; writing – original draft. **Corwin Rhyan:** Conceptualization; data curation; formal analysis; validation; investigation; visualization; methodology; writing – review and editing. **Mona Hanna-Attisha:** Conceptualization; resources; supervision; funding acquisition; project administration; writing – review and editing.

DATA AVAILABILITY STATEMENT

Due to privacy concerns, the data used in this study are unavailable from the authors but may be released upon request at EGLE's discretion.

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