Estimating Impacts of LCRR's Fifth-Liter Sampling and Find-and-Fix Requirements on Large Water Systems - Supplemental Information

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Abstract

Methods and Results - Additional Information

System Information

The Philadelphia Water Department (PWD) is a combined water and wastewater utility that serves a population of over 1.6 million through over 450,000 service connections. PWD is a surface water system that uses orthophospate as its corrosion control treatment (CCT)

Since the promulgation of the original LCR in 1991, PWD has conducted 14 rounds of LCR compliance sampling through the end of 2020, with only the very first round (before the implementation of optimized corrosion control treatment) exceeding the LCR AL[1]. Over the course of the last three decades, PWD has seen continued decreases in the 90th percentile statistic for the LCR and overall shrinking of the lead result distribution[1]. PWD conducted three LCR compliance sampling rounds between 2016 and 2019 (2016, 2017, and 2019). These three sampling rounds were used to estimate L5 sample results. In addition, PWD conducted another round of LCR monitoring in 2022. During the 2022 monitoring round, L1 and L5 samples were collected from all homes that participated. The 90th percentile value from the 2022 L5 samples was used to compare to the estimated L5 90th percentile results from the 2016-2019 data simulations.

DC Water is a combined water and wastewater utility that purchases its treated drinking water. DC Water has been on a bi-annual standard monitoring schedule since 2003. Starting in 2004, DC Water began dosing orthophosphate at a concentration of 3.2 mg/L and reducing to 2.4 mg/L as its corrosion control strategy. Since starting orthophosphate treatment, DC Water has seen steady declines in its 90th percentile levels for lead. Between 2018 and 2020, DC Water completed 6 LCR sampling rounds where both the L1 and L5 samples were collected for each home. These six sample rounds were included in this analysis. Over 100 samples were collected during each of the six sampling rounds, with 118 being the highest number of homes sampled. DC Water utilizes a fill-and-dump method to collect L5 samples where customers are instructed to fill and dump the second 1 liter bottle three times (liters 2-4) before collecting the L5 sample. In total, 651 compliance samples from 223 homes were collected over the course of the six sample rounds. Of these samples, 14 did not have a paired L5 sample. The L1 samples without paired L5 samples were excluded from the analysis.

Utility B is a surface water utility that utilizes pH adjustment (with a target pH of 8.9) as its corrosion control treatment. Utility B collected paired L1 and L5 lead samples from January 2021 through June 2021. To collect the samples, Utility B provided five 1-liter bottles labeled 1 through 5 to customers participating in the lead compliance monitoring sampling and oral and written instructions were provided to customers on how to collect the samples sequentially. All sample locations were confirmed to have lead service lines before sampling.

Method Workflow

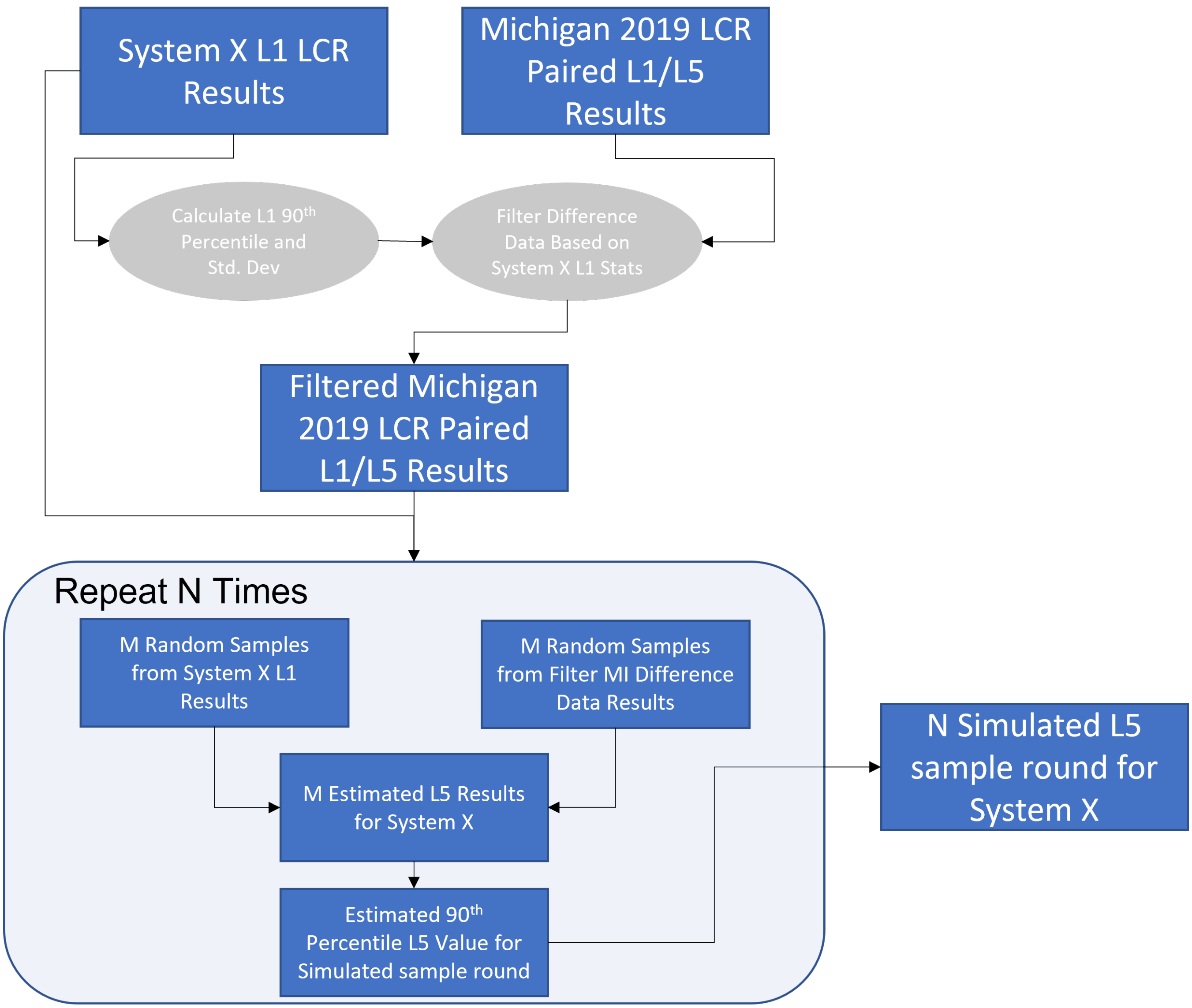

Figure S1: Bootstrap Method for Estimate L5 lead results using L1 lead results and L5-L1 difference data from MI 2019 LCR Sampling Round.

MLE for selecting difference data distribution

For all Michigan systems that participated in the 2019 MI sampling round, differences were calculated between the L5 and L1 lead levels (L5-L1). Differences greater than 100 ppb between L5 and L1 samples were excluded under the assumption that differences of that size are likely caused by particulate lead which is much harder to predict its occurrence. Figure S8 shows the distribution of simulated 90th percentile results for DC Water with and without differences greater than 100 ppb included. From this figure, it is clear that excluding these value did not significantly impact estimation of 90th percentile values. Reference distributions (Gamma, Log-Normal, and Normal) were fit to the difference data using Maximum Likelihood Estimation (MLE)[2]. Difference data was transformed by adding 100 to all values to be able to fit gamma and log-normal distributions. The reference distributions were compared using the Akaike information criterion (AIC) to determine the best fit. In addition to fitting the distribution of differences using MLE, differences between L5 and L1 paired samples were also estimated by sampling directly from the distribution of differences using bootstrap analysis. The two methods for simulating difference data between L1 and L5 data were evaluated on DC Water to assess which provided a more accurate estimate of L5 results.

Using Michigan's 2019 LCR compliance sampling data, which required both L1 and L5 samples for homes with LSL, differences were calculated for every paired L1 and L5 set of samples. Using the compliance group determination method outlined in Masters et al.[3], only systems that had a 90th percentile value less than 5 ppb in their L1 samples were used in this analysis. This was done under the assumption that only systems currently achieving levels similar to the testing systems should be included. It is assumed that systems with higher L1 sample results will have difficulty in their ability to control lead in any samples. Fitting distributions for the differences using normal, log-normal, and gamma distributions resulted in AIC values of 11,258, 11,779, and 11,521, respectively. Given the lowest AIC score, the normal distribution was chosen as reference. The three distributions and the data they approximate can be seen together in Figure S2. From this figure, the true distribution of differences is highly centered around zero with very short tails. All three reference distributions are wider spread than the true distribution. The wider tails of the selected normal distribution resulted in a significant over-estimation of the L5 90th percentile (Figure S9). Due to this overestimation by the fit normal distribution, difference results were sampled directly from the Michigan difference data to avoid overestimating L5 results for all further simulations.

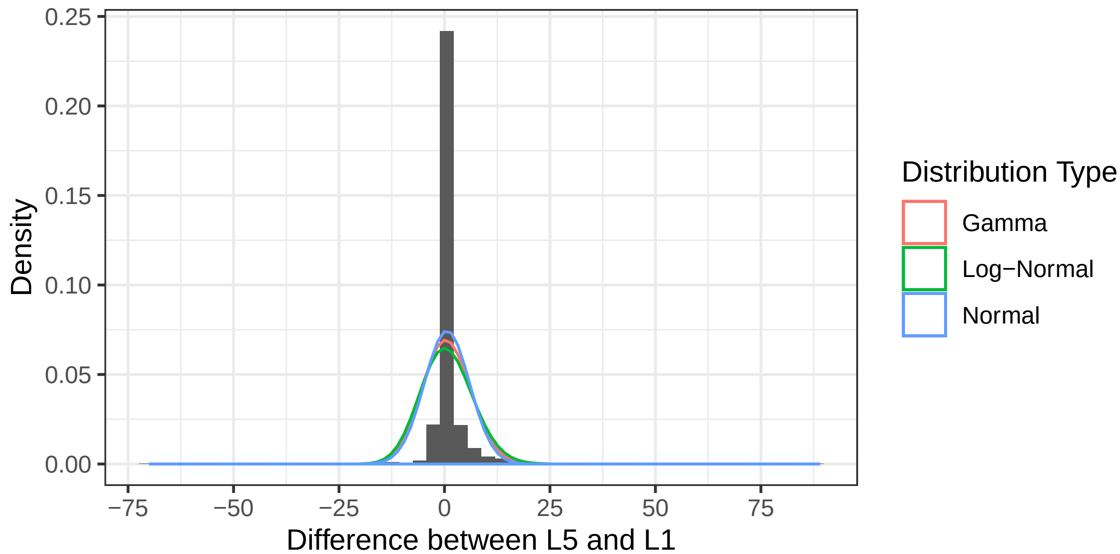

Figure S2: Distribution of differences between L1 and L5 samples in Michigan's 2019 LCR compliance sampling. The distributions fit to the data

DC Water Simulation Figures

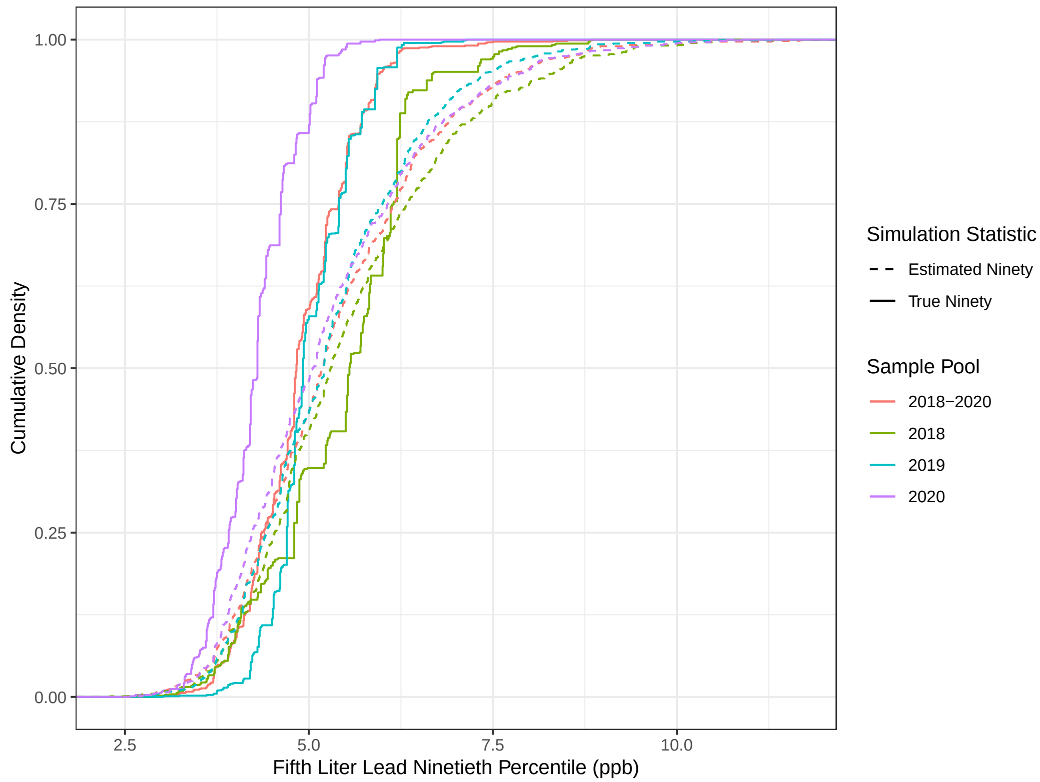

Figure S3: Cumulative density of 90th percentile L5 lead levels from true and estimated simulated results for DC Water

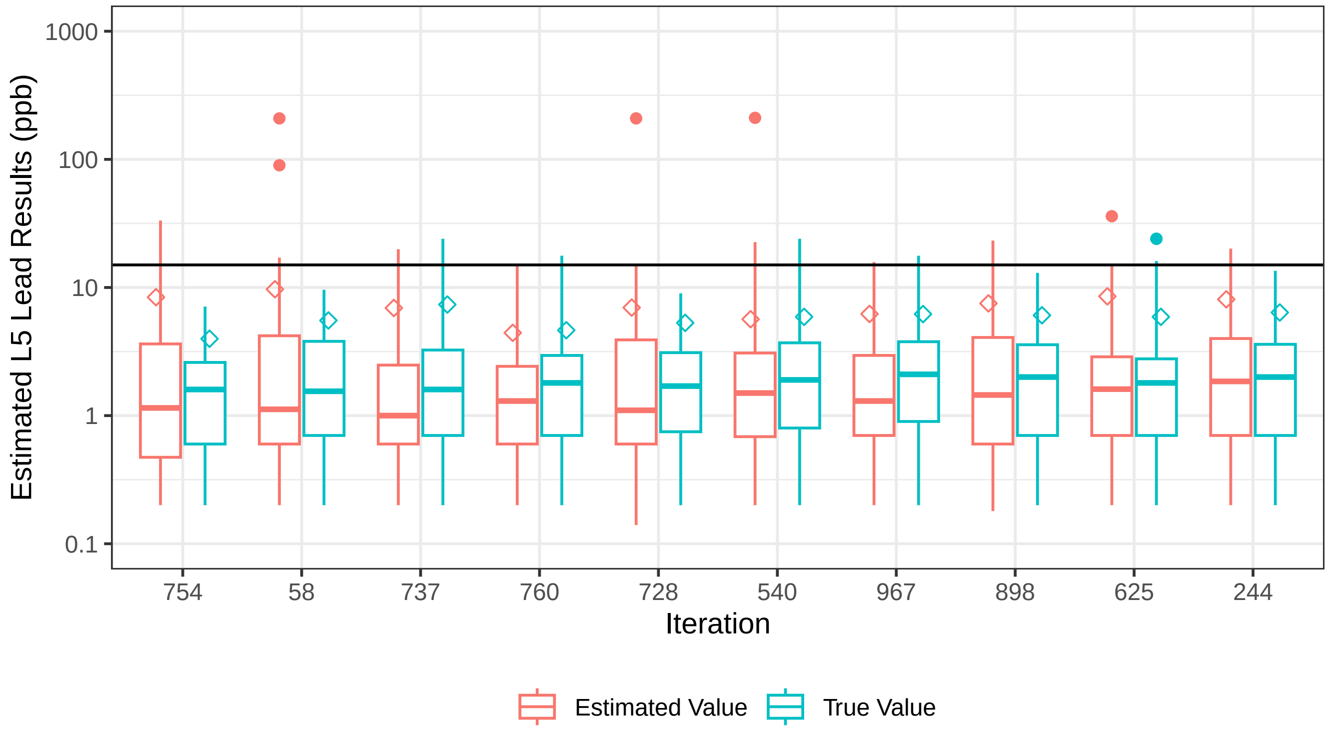

Figure S4: Ten randomly selected simulated sampling rounds for data sampled from 2018-2020 showing the distribution for both real and estimated L5 lead results. The black horizontal line represents the LCRR 15 ppb Action Level.

Utility B Simulation Figures

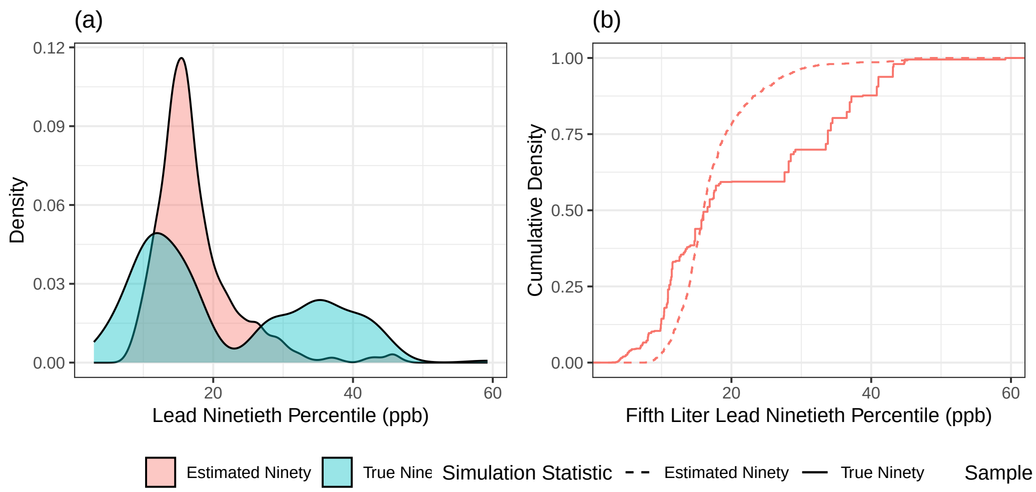

Figure S5: (a) Distributions of the 'true' and 'estimated' 90th percentile values for Utility B's 2021a sample round. (b) Cumulative density function plot for both the 'true' and 'estimated' 90th percentile values for Utility B's 2021a sample round.

PWD Simulation Figures

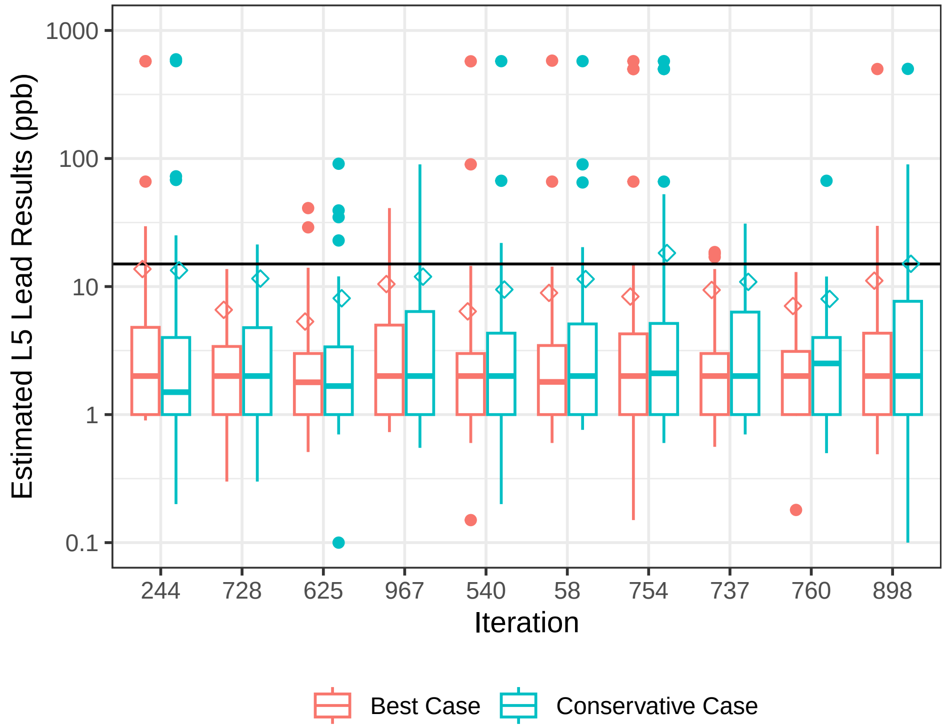

Figure S6: Distribution of estimated L5 results from 10 randomly selected LCRR sampling round simulations for PWD.

Table S1: Lead Distribution table for simulated L5 samples from 5 randomly selected bootstrap iterations. These randomly selected iterations are shown for both the 'best case' and 'conservative case' scenarios.

	Best Case					Conservative Case				
Range of Lead Results	Iteration 244	Iteration 625	Iteration 728	Iteration 737	Iteration 898	Iteration 244	Iteration 625	Iteration 728	Iteration 737	Iteration 898
<=5	81.0%	93.0%	84.0%	86.0%	83.0%	84.0%	90.0%	82.0%	79.0%	75.0%
>5 and <=10	8.0%	1.0%	14.0%	6.0%	7.0%	5.0%	4.0%	9.0%	11.0%	12.0%
>10 and <=15	6.0%	4.0%	2.0%	5.0%	5.0%	4.0%	2.0%	6.0%	8.0%	5.0%
>15 and <=30	2.0%	1.0%	0%	3.0%	4.0%	3.0%	1.0%	3.0%	1.0%	5.0%
>30	3.0%	1.0%	0%	0%	1.0%	4.0%	3.0%	0%	1.0%	3.0%
Summary Statistics										
50th Percentile	1.35	1	1	1.21	2	1	1	1	1.15	2
90th Percentile	10.27	4.03	6.34	6.88	8.72	10.98	5.06	8.16	8.9	12.36
Variance	6519.37	29.18	7.49	15.05	2497.38	6811.84	112.36	19.05	23.41	2572.4
n	100	100	100	100	100	100	100	100	100	100

Simulation results with differences greater than 100ppb included

Difference results greater than 100 ppb were removed from the difference data sets. Elevated lead levels above 100 ppb are often associated with particulate lead release and are more difficult to predict the occurrence of[4,5]. As a result, these differences that would have resulted in a lead level over 100 ppb while the L1 result was not elevated were removed to prevent inaccurate prediction of particulate lead release. The simulation results shown in Figure S**??** demonstrates how including vs excluding difference results over 100 ppb impact the estimation of L5 90$^{\text{th}}$ percentile results.

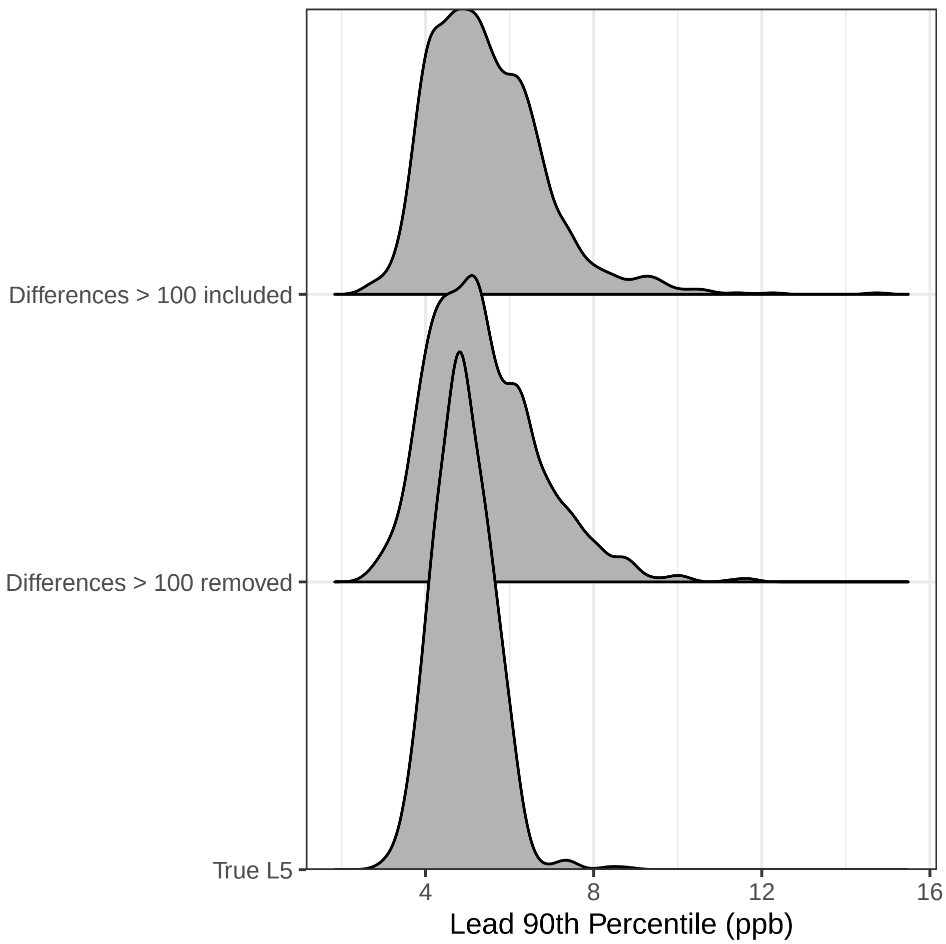

Figure S7: Simulation results for DC water when L5-L1 differences were sampled when including and excluding difference values greater than 100 ppb.

Parametric vs non-parametric estimation of results

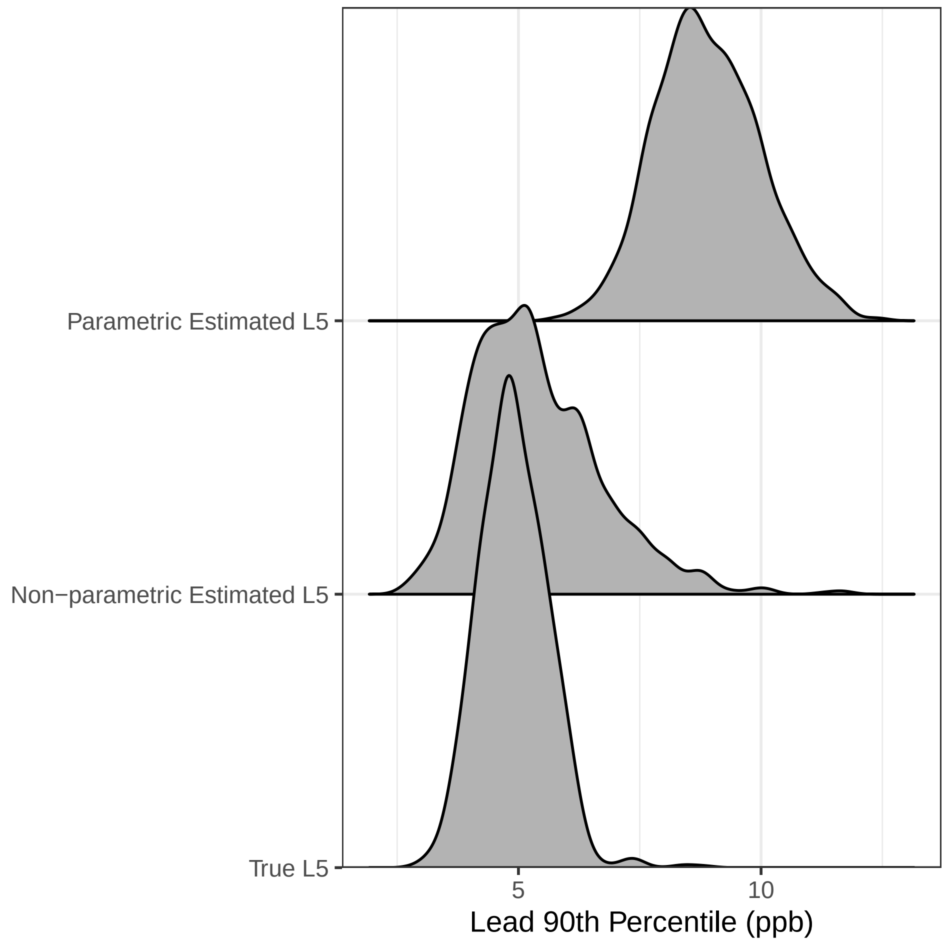

Figure S8: Simulation results for DC water when L5-L1 differences were sampled from a parametric normal distribution fit to Michigan difference data vs when differences were sampled directly from te difference dataset.

Impact of L1 Sample Size on Simulation Results

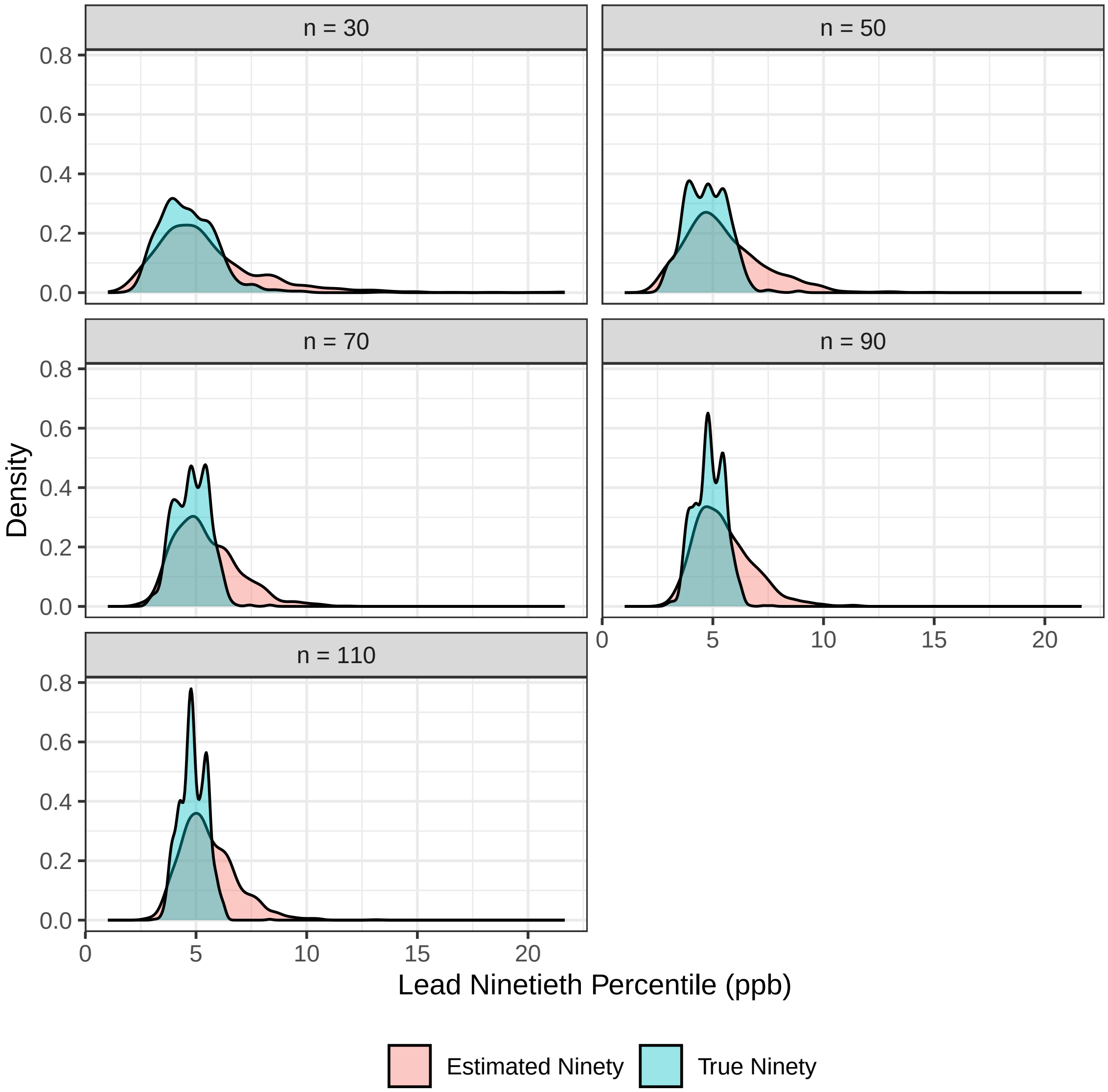

Figure S9: Simulation results for DC Water using different L1 sample sizes. 1000 simulations were performed for each sample size using all DC Water L1 data as the source.

References

(1) Bradley, T.; Horscroft, N. Using Historical LCR and Water Quality Data to Evaluate Corrosion Control Treatment. *Journal - American Water Works Association* **2018**. https://doi.org/10.1002/awwa.1143.

(2) Delignette-Muller, M. L.; Dutang, C. fitdistrplus: An R Package for Fitting Distributions. *Journal of Statistical Software* **2015**, *64* (4), 1–34.

(3) Masters, S. V.; Bradley, T. C.; Burlingame, G. A.; Seidel, C. J.; Schmelling, M.; Bartrand, T. A. What Can Utilities Expect from New Lead Fifth-Liter Sampling Based on Historic First-Draw Data? *Environmental Science & Technology* **2021**, *55* (17), 11491–11500. https://doi.org/10.1021/acs.est.1c00421.

(4) Masters, S.; Welter, G. J.; Edwards, M. Seasonal Variations in Lead Release to Potable Water. *Environmental Science & Technology* **2016**, *50* (10), 5269–5277. https://doi.org/10.1021/acs.est.5b05060.

(5) Clark, B.; Masters, S.; Edwards, M. Profile Sampling to Characterize Particulate Lead Risks in Potable Water. *Environmental science & technology* **2014**, *48* (12), 6836–6843. https://doi.org/10.1021/es501342j.