Milwaukee Water Works
Safe, Abundant Drinking Water.

Madison - Milwaukee Lead Copper Rule (LCR) Data Comparison (2011-2017) and Beyond

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Quick Facts

- Lead and copper can cause physical and mental health effects. Children under the age six and women who are pregnant, or may become pregnant, are especially at risk.
- The Lead and Copper Rule (LCR) was established in 1991 by the United States Environmental Protection Agency (US EPA) to protect public health by minimizing the amount of lead and copper in public water systems (PWSs).
- The LCR requires PWSs to comply with sampling and monitoring requirements and to meet the current action levels for lead (15 ppb) and copper (1300 ppb) in drinking water.
- While new technologies are being developed, optimized corrosion control treatment (OCCT) and lead service line replacement (LSLR) programs are two approaches for reducing lead and copper in tap water.

Executive Summary

Following implementation of the LCR, Madison and Milwaukee took action to reduce lead and copper in their PWS. In 1996, the city of Milwaukee, in conjunction with the EPA and Wisconsin Department of Natural Resources (WDNR), implemented OCCT using orthophosphate and has continued this treatment to present day. In 2001, the city of Madison began replacing all known LSLs (approximately 8,000) and completed the program in 2010. As such, LCR compliance sampling from Madison in the years 2011, 2014, and 2017 consisted only of single family homes with copper service lines. Conversely, LCR compliance sampling in Milwaukee during those same years consisted of single family homes with LSLs with OCCT. Lead and copper comparisons revealed that lead concentrations were not significantly different between Madison and Milwaukee. In addition, copper concentrations were significantly lower in Milwaukee tap water compared to Madison. These data show that OCCT is highly effective at reducing both lead and copper levels in tap water.

Introduction

The Lead and Copper Rule (LCR) was established by the United States Environmental Protection Agency (USEPA) in 1991 to control the amount of lead and copper in drinking water. The LCR states that if lead concentrations in water exceed 15 ppb (i.e. $\mu g\ L^{-1}$), or if copper concentrations exceed 1300 ppb, in 10% of the samples collected, the public water system (PWS) must take action to reduce lead and copper levels in the water and alert the public of steps they can take to protect their health. The most common immediate action for reducing lead and copper concentrations in water is by using corrosion control. However, the removal of all public and private lead service lines is seen as the long-term solution.

Madison and Milwaukee present an interesting case study to examine lead and copper levels in drinking water because they have different source water types and watershed concerns restricting how they treat water. In addition, in response to the LCR of 1991, each PWS took different actions in reducing lead and copper in their drinking water. The city of Madison receives their drinking water from ground water and has strict policies on discharging nutrients in the watershed. Several corrosion control options were tested, including sodium silicate and polyphosphate blends, but none reduced lead levels to below the action level. Orthophosphate was later found to significantly reduce lead levels in Madison drinking water, but was dismissed due to concerns that the phosphorus loading would interfere with the biological treatment process of the wastewater treatment plant. Therefore, on January 1st, 2001, Madison began a lead service line replacement (LSLR) program to remove all known LSLs in the city. By 2010, more than 8,000 LSLs were removed.

Milwaukee receives its drinking water from a surface water source, Lake Michigan, and at the levels of phosphate needed for corrosion control, no strict policies currently prevent orthophosphate from being used in the Milwaukee area watersheds. Thus, Milwaukee Water Works (MWW) established a protocol—along with the Wisconsin Department of Natural Resources (WDNR)—to implement optimized corrosion control treatment (OCCT) of MWW drinking water. Milwaukee also established an LSLR program beginning January 1st, 2017, but to date, approximately 73,000 LSLs remain in the city.

Both Madison and Milwaukee are subject to LCR compliance and have collected samples for LCR since 1992. After 2002, Milwaukee was allowed reduced sampling and since then, has collected lead samples from at least 50 tier 1 sites every three years. For Milwaukee, tier 1 sites are designated single family homes with private side LSLs. Madison was allowed reduced sampling in 2014, but unlike Milwaukee, tier 1 sites consist of single family homes with copper lines and lead solder (since all LSLs have been removed). Madison and Milwaukee LCR sampling has remained the most consistent from 2011-2017 and all data are fully and freely available online. These datasets should be helpful in establishing baseline lead and copper concentrations when lead/copper service lines are present and provide additional information on the effectiveness of OCCT in lead/copper service lines. This comparison may prove beneficial since the WDNR, EPA, and Milwaukee Water Works are currently in the process of revising how LCR compliance is sampled and evaluated.

Table 1. General characteristics of Madison and Milwaukee Public Water Systems and current sampling locations for Lead Copper Rule (LCR) compliance.

Variable	Madison	Milwaukee
Source Water	Ground	Surface
Corrosion control	No	Yes
Lead service lines	No	Yes
Current LCR sites	52	50
Sample frequency	Every three years	Every three years
Current tier 1 sites	Copper w/ lead solder	Lead service lines
Potential lead sources	Lead solder, lead plumbing, lead meters, source water	Lead pipe, lead solder, lead plumbing, lead meters, source water

Data and results

Lead and copper data comparisons for Madison and Milwaukee LCR compliance 2011-2017 are summarized in Tables 2 and 3, respectively. In addition, each dataset is summarized using a boxplot analysis (Figures 1 and 2), which is described in detail below.

Lead comparison between Madison and Milwaukee

In each of the LCR compliance years being compared, Madison had 90th percentile lead levels that were lower than Milwaukee (Table 2 and Figure 1). However, none of the datasets were significantly different based on analysis of variance, likely due to the fact that more than 80% of all samples collected contained < 5 μg L^{-1} lead. As a result, the median values for both Madison and Milwaukee—1.33 and 1.88 μg L^{-1}, respectively—were very similar. Furthermore, Madison and Milwaukee each had an average of 35% and 27% of samples, respectively, that were < 1 μg L^{-1} of lead, which was near the method detection limit for both utilities. Thus, 90th percentile and mean concentrations of lead in both cities have been skewed by a few sample sites, which is characteristic of a power-law probability distribution (*see* Supplemental Information for example and explanation), and not representative of the larger dataset. For example, one anomolous sample in Milwaukee in 2017 measured 130 μg L^{-1} lead, which increased the average lead concentration from 3.48 to 6.01 μg L^{-1}. It was later discovered that location had remained vacant for an extended period of time and had previously measured 1.9 and 2.4 μg L^{-1} lead in 2011 and 2014, respectively. In total, Madison has had three samples > 15 μg L^{-1} lead, while Milwaukee has had five; however, neither city has approached the EPA 90th percentile action level since OCCT and LSL replacements have been implemented.

Copper comparison between Madison and Milwaukee

Unlike lead, copper concentrations were significantly higher in Madison drinking water than in Milwaukee (Table 3 and Figure 2). This is not surprising since Madison samples from homes with copper pipes and lead solder as their tier 1 sampling sites. No samples collected from Madison or Milwaukee exceeded the EPA action level of 1300 μg L^{-1} copper. Unlike the lead samples collected, Madison copper levels followed what is called a normal probability distribution (*see* Supplemental Information for example and explanation). Thus, the average and median concentrations should converge on each other over time, and the dataset outliers will occur at both the very low and very high copper levels.

Because Milwaukee tier 1 sites were comprised of lead lines from 2011-2017, the majority of sites had very low copper levels (e.g. < 10 μg L^{-1} copper) with only a few sites approaching 100 μg L^{-1}. However, prior to 2004, EPA tier 1 categories could consist of either lead or copper service lines. Thus, Milwaukee sampling sites included single family homes with either lead or copper service lines. Varying degrees of copper and lead sampling occurred from 1993-2004 with two important aspects to note: 1) Milwaukee began corrosion control treatment in 1996 providing a pre- and post-OCCT comparison of lead and copper levels, and 2) the number of copper service lines sampled varied greatly during this time, ranging from 4-104 samples per year, with all copper service line sampling being eliminated from the tier 1 category after 2004.

As expected, lead concentrations from Milwaukee copper service lines were very low (i.e. < 5 μg L^{-1}; Table 4 and Figure 3) and comparable to current lead levels in Madison copper service lines. Unexpectedly though, Milwaukee copper concentrations from copper service lines were much lower than samples collected from Madison and followed a different probability distribution with just a few high concentrations being observed. After 1996, most copper levels observed were very low (e.g. < 200 μg L^{-1}) with median values an order of magnitude less than those observed in Madison copper service lines.

Therefore, it appears that OCCT signficantly reduced both lead and copper concentrations in both lead and copper service lines in Milwaukee after 1996.

Discussion

Surprisingly, considering Madison has removed all known LSLs, lead levels in Madison and Milwaukee drinking water are very similar. This raises many questions, but of immediate importance one could ask what is the major source of lead in Madison drinking water, and if Milwaukee removes all LSLs like Madison, what is a realistic lead concentration that could be achieved in Milwaukee drinking water? If we first consider Madison drinking water, it is likely that lead solder and other home plumbing contributes to low level concentrations of lead in the tap water, and unidentified sources of lead from lead plumbing or meters could contribute to higher levels of lead. Additionally, preliminary studies have suggested that Madison ground water, which is higher in manganese (Mn) and iron (Fe), can form lead precipitates that build up on pipes and eventually release into tap water resulting in unusually high lead results. As such, Madison will likely always have a few samples with high lead concentrations as suggested by a non-normal power-law probability distribution. Copper, however, has fewer sources and may not form these stochastic precipitates. Thus, copper concentrations in Madison should remain within the current “normal” range of 120-140 $\mu g\ L^{-1}$.

Milwaukee still has LSLs, and thus, they are a likely source of some lead in drinking water, and the presence of lead plumbing and lead solder within homes may be the cause of higher lead concentrations. Because of Lake Michigan source water characteristics, and the proven success of OCCT in Milwaukee drinking water, it is highly likely that the removal of LSLs in Milwaukee will result in reduced lead concentrations in tap water (e.g. 1-3 $\mu g\ L^{-1}$), possibly even lower than Madison water. In addition, as lead is replaced with copper, Milwaukee can expect copper concentrations to be lower than Madison drinking water as well since it was observed that copper concentrations were drastically reduced in copper service lines following OCCT implementation in 1996. Additional sampling in Milwaukee should show that the majority of homes have low lead levels with a very small percentage approaching or exceeding the EPA action level due to internal plumbing.

Table 2. Lead and Copper Rule (LCR) statistics for Madison and Milwaukee lead (Pb) levels collected tri-annually from 2011-2017.

Municipality	Statistic	2011	2014	2017
Madison Lead ($\mu g\ L^{-1}$)	*n* =	201	52	52
	90th percentile	2.96	3.52	3.16
	Minimum	0.50	0.50	0.23
	Mean	1.80	1.92	2.11
	Standard Error	0.16	0.24	0.50
	Median	1.21	1.44	1.33
	Maximum	20.6	10.4	25.5
Milwaukee Lead ($\mu g\ L^{-1}$)	*n* =	51	51	50
	90th percentile	6.40	8.20	7.20
	Minimum	1.00	1.00	0.40
	Mean	3.02	3.18	6.01
	Standard Error	0.48	0.51	2.61
	Median	1.80	1.90	1.95
	Maximum	22.0	21.0	130

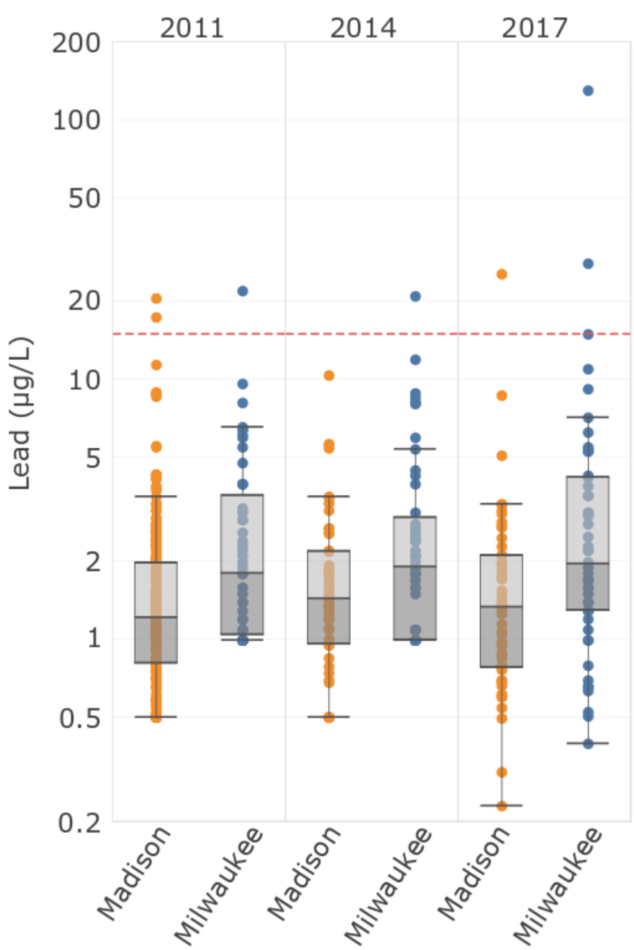

Figure 1: Boxplot analysis of Madison and Milwaukee lead concentrations from LCR samples collected tri-annually from 2011-2017. For boxplot description: center line = median, box edges = 25th and 75th percentiles, whiskers = minimum and maximum values not considered outliers, and circles are outliers. The dashed line represents the EPA 15 $\mu g\ L^{-1}$ action level for lead. No significant differences were observed between Madison and Milwaukee using an analysis of variance with a significance cut-off of $p < 0.05$.

Table 3. Lead and Copper Rule (LCR) statistics for Madison and Milwaukee copper (Cu) levels collected tri-annually from 2011-2017.

Municipality	Statistic	2011	2014	2017
Madison Copper (μgL^{-1})	n =	201	52	52
	90th percentile	172	185	169
	Minimum	6.00	35.4	75.0
	Mean	121	142	132
	Standard Error	3.23	6.35	4.25
	Median	116	133	129
	Maximum	493	292	242
Milwaukee Copper (μgL^{-1})	n =	51	51	50
	90th percentile	38.0	38.0	46.0
	Minimum	1.00	1.00	0.60
	Mean	17.4	16.9	18.5
	Standard Error	4.22	3.30	3.43
	Median	5.90	6.80	8.90
	Maximum	190	130	110

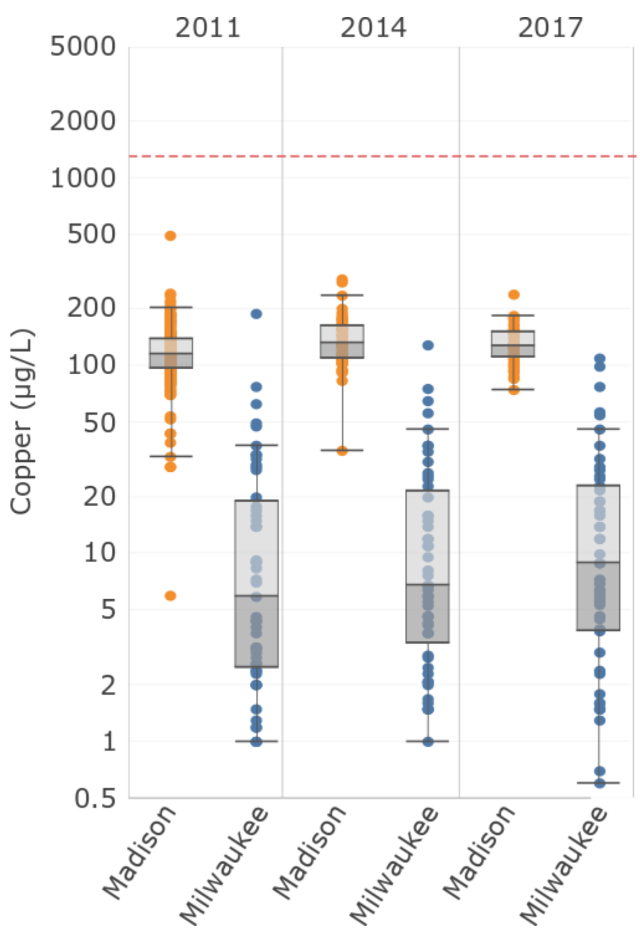

Figure 2: Boxplot analysis of Madison and Milwaukee copper concentrations from LCR samples collected tri-annually from 2011-2017. For boxplot description: center line = median, box edges = 25th and 75th percentiles, whiskers = minimum and maximum values not considered outliers, and circles are outliers. The dashed line represents the EPA 1300 µg L^{-1} action level for copper. No samples exceeded the copper action level. Copper concentrations were significantly higher in Madison than in Milwaukee using an analysis of variance with a significance cut-off of $p < 0.05$.

Table 4. Lead and copper statistics from Milwaukee sites with **copper service lines and lead solder**. Note, the implementation of optimized corrosion control treatment (OCCT) using orthophosphate began after 1996.

Variable	Statistic	1993	1995	1997	1998	1999	2001	2002	2003	2004
Lead ($\mu g\ L^{-1}$)	n =	50	49	104	27	25	101	99	26	4
	90th percentile	5.00	4.00	1.00	1.40	1.60	1.90	2.10	2.10	**
	Minimum	1.00	1.00	1.00	0.73	0.73	0.73	0.66	0.78	2.00
	Mean	3.58	2.57	1.22	1.04	1.58	1.30	1.37	1.86	2.00
	Standard error	0.40	0.54	0.07	0.20	0.58	0.22	0.11	0.59	0.00
	Median	3.00	1.00	1.00	0.73	0.73	0.73	1.30	0.82	2.00
	Maximum	17.0	21.0	5.00	6.00	15.0	17.0	8.70	16.0	2.00
Copper ($\mu g\ L^{-1}$)	n =	50	49	104	27	25	101	99	26	4
	90th percentile	300	670	150	112	114	71.0	110	61.0	**
	Minimum	10.0	20.0	2.00	2.20	3.50	3.40	1.80	4.50	6.10
	Mean	137	322	74.5	93.9	52.7	33.7	41.8	46.8	28.5
	Standard error	18.1	43.9	7.62	34.5	8.34	3.47	7.97	21.2	19.5
	Median	100	195	52.5	55.0	42.0	19.0	18.0	13.0	10.5
	Maximum	640	1450	486	905	134	170	563	540	87.0

**No 90th percentile calculated due to only 4 copper sites being sampled in 2004.

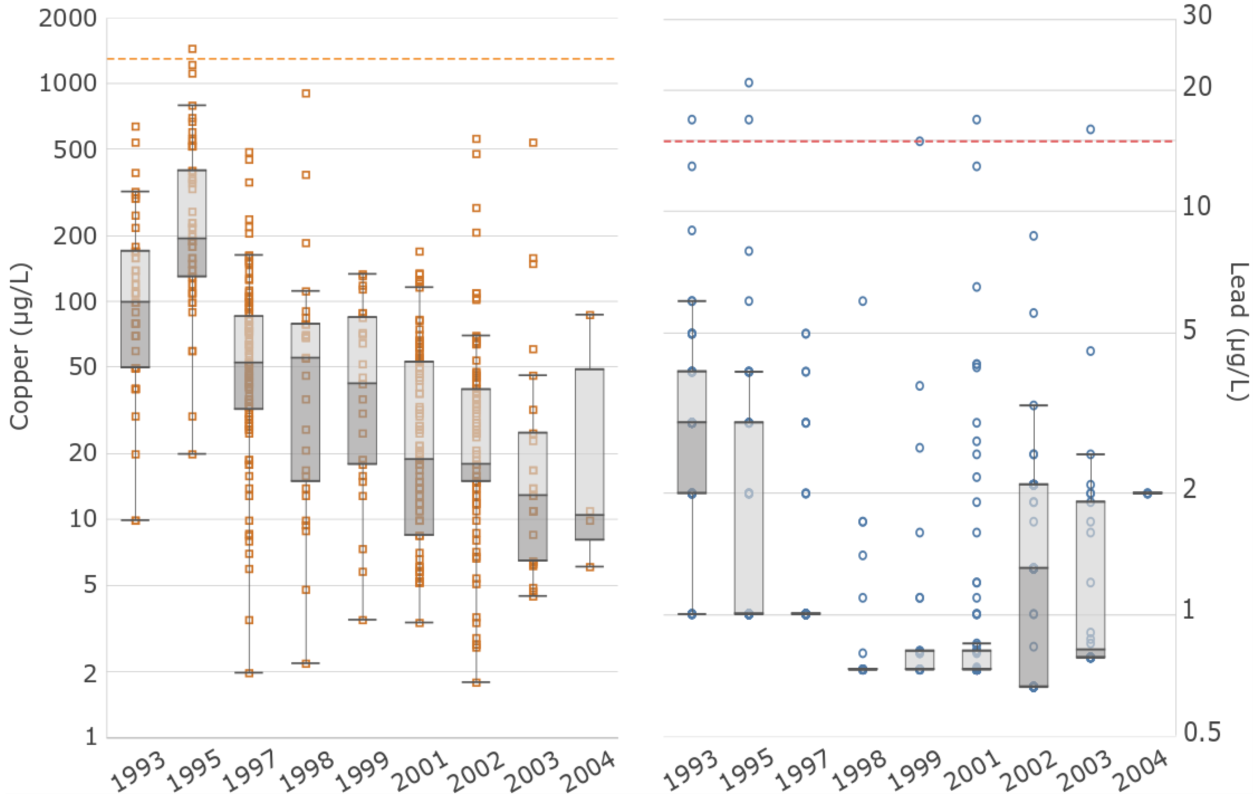

Figure 3: Boxplot analysis of Milwaukee copper (left) and lead (right) concentrations from LCR samples collected from single family homes with **copper service lines** from 1993-2004. For boxplot description: center line = median, box edges = 25th and 75th percentiles, whiskers = minimum and maximum values not considered outliers, and circles are outliers. The dashed lines represent the 1300 µg L^{-1} and 15 µg L^{-1} action levels for copper (left) and lead (right), respectively. Note, the implemenation of optimized corrosion control treatment (OCCT) using orthophosphate began after 1996.

Supplemental information

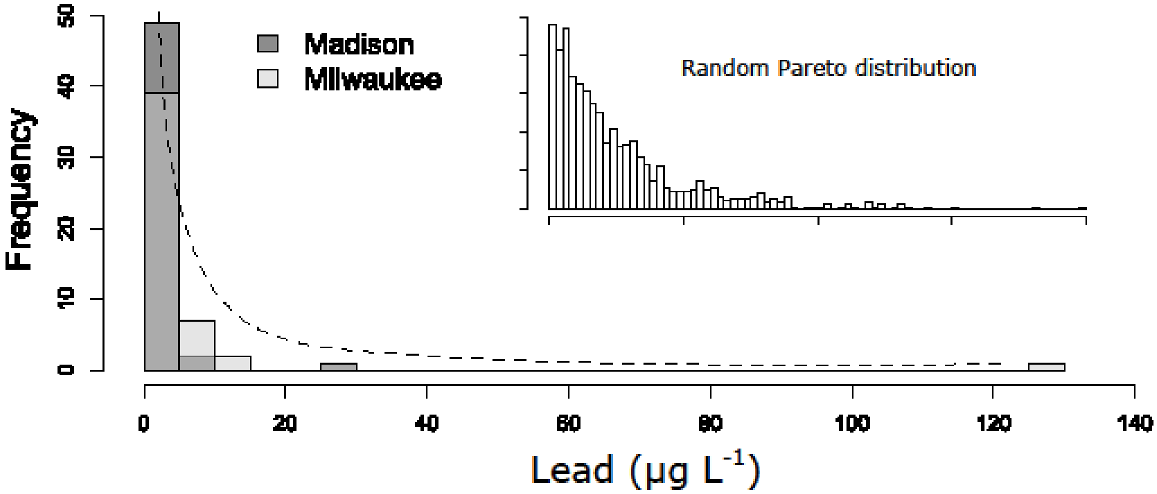

Figure S1: Histogram showing the distribution of lead concentrations measured in Madison and Milwaukee as part of 2017 LCR compliance sampling. Both sample sets represent a Pareto distribution (power-law probability distribution), meaning that a few samples can dominate the sample set, the samples are said to not be "normal," and the median value is more likely to be represenatitive of the dataset than the average. For example, in Milwaukee, nearly 40 of the 50 samples collected were less than 5 µg L^{-1} total lead, but one sample at 130 µg L^{-1} greatly influenced the average value. Similarly, 51 of 52 lead samples in Madison were < 10 µg L^{-1}. In the upper right corner is a randomized Pareto distribution of 1000 samples generated using R Statistical Software.

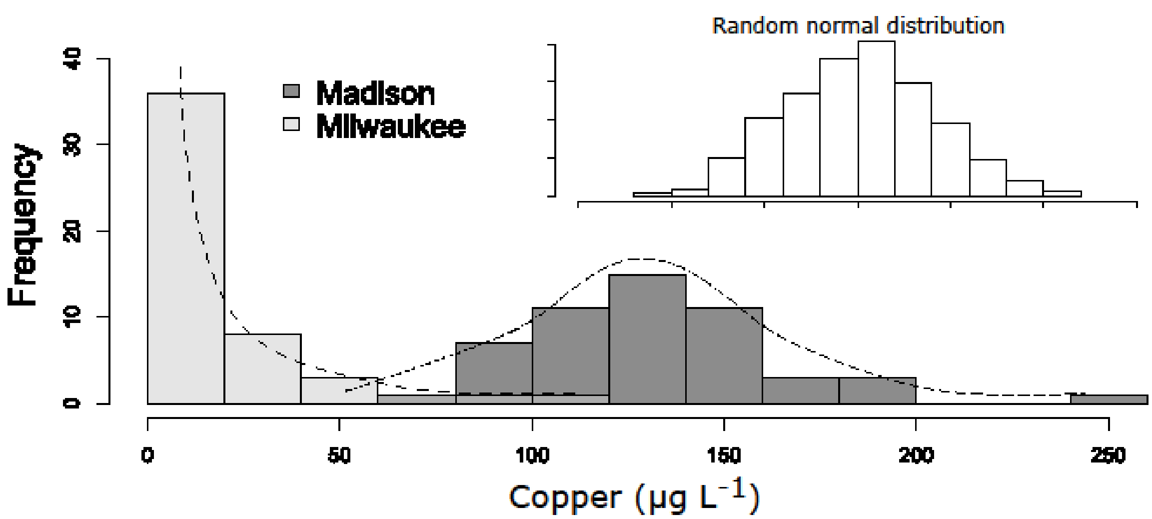

Figure S2: Histogram showing the distribution of copper concentrations measured in Madison and Milwaukee as part of 2017 LCR compliance sampling. As with lead (Figure A1), Milwaukee samples represent a Pareto distribution. However, Madison copper samples represent what is referred to as a Gaussian, or normal, distribution. In this case, the samples are said to be truly random and the median and average values should be similar. In the upper right corner is a randomized normal distribution of 1000 samples generated using R Statistical Software.