DAVID A. CORNWELL

How Have We Done in Reducing Lead in Water Since the LCR?

WITH A PROPOSAL TO UPDATE THE LEAD AND COPPER RULE EXPECTED IN 2019, IT IS A GOOD TIME TO EVALUATE IMPROVEMENTS SINCE THE 1991 RULE TOOK EFFECT.

It has been 27 years since the Lead and Copper Rule (LCR) was enacted (USEPA 1991); a proposal from the US Environmental Protection Agency (USEPA) to update those regulations is expected in early 2019. There has been renewed interest in water lead levels given recent localized events that have spotlighted the issue; with this in mind, it is an appropriate time to reflect on how successful the water industry has been in reducing lead levels in drinking water.

Much of the current attention on lead focuses on communities that have lead service lines. Lead service lines can be a major source of lead in water, but home brass fixtures and old copper with lead or tin solder are also significant lead contributors. While there are many resources available for utilities (e.g., www.awwa.org/resources-tools/water-knowledge/lead.aspx), many consumers unfortunately do not understand the source of lead that ends up in the drinking water at consumer taps; too often, people believe that the lead is in the water coming from the city's water treatment plant. Despite the industry's efforts to educate the public, recent events that heightened awareness have also muddled the story with politics and management issues. Many utilities have been put on the defensive for practices related to the LCR. A water system's treatment and distribution implicitly require the trust of the public, so how has the industry done collectively on this front?

Layout imagery by Shutterstock.com/Photographee.eu, science photo

Installation of lead service lines, which are often the major contributor of lead in water when they are present, was not prohibited in the United States until the 1986 Safe Drinking Water Act (SDWA) requirements took effect, although many utilities had stopped using them prior to that time. Historically, lead lines were highly desirable because they lasted much longer than iron pipes and were relatively easy to install.

However, pure lead service lines are not the only type of lead pipe used for service lines. For example, an interesting and underreported occurrence of lead lines is when a lead tube was inserted inside an iron or steel pipe. These lead-lined steel pipes were used as service lines, according to a 1917 *Journal of the New England Water Works Association* article (NEWWA 1917). These lead-lined pipes were used to get the "desired" qualities of lead, but they were less expensive than lead alone. Unfortunately, from the outside of the pipe, there is no way to know whether it has a lead liner inside because the pipe has the appearance and properties of an iron or steel pipe.

The scanning electron microscopy/energy dispersive spectroscopy elemental analysis shown in Figure 1 illustrates part of a lead-lined iron pipe that was analyzed by Cornwell Labs and the University of Florida. A spot scan was conducted at the inner, water-contact area of the pipe and at the main pipe wall section. As shown in the figure, the elemental lead peak is very high at the inner layer, while the iron peak is low. Moving from the lead liner to the main pipe, the lead content drops, and the iron dominates. These pipes seem to have been most common in New England, but many have also been found in New Jersey. The sidebar on page 32 contains an interesting quote on this topic from a water utility manager in 1917, as reported in the *Journal of the New England Water Works Association* (NEWWA 1917).

A DAUNTING TASK

Unfortunately, many utilities did not keep good records of lead service line installations over the years, so it is difficult to know how many lead or lead-lined service lines are still in use. In addition, galvanized lines can be a source of lead (Clark et al. 2015). Add in the unknown presence of lead goosenecks, and it becomes clear what a daunting task it is to fully know the extent of lead in a distribution system. However, it is assumed that homes built after 1986

FIGURE 1 SEM/EDS point scan of a lead-lined iron pipe

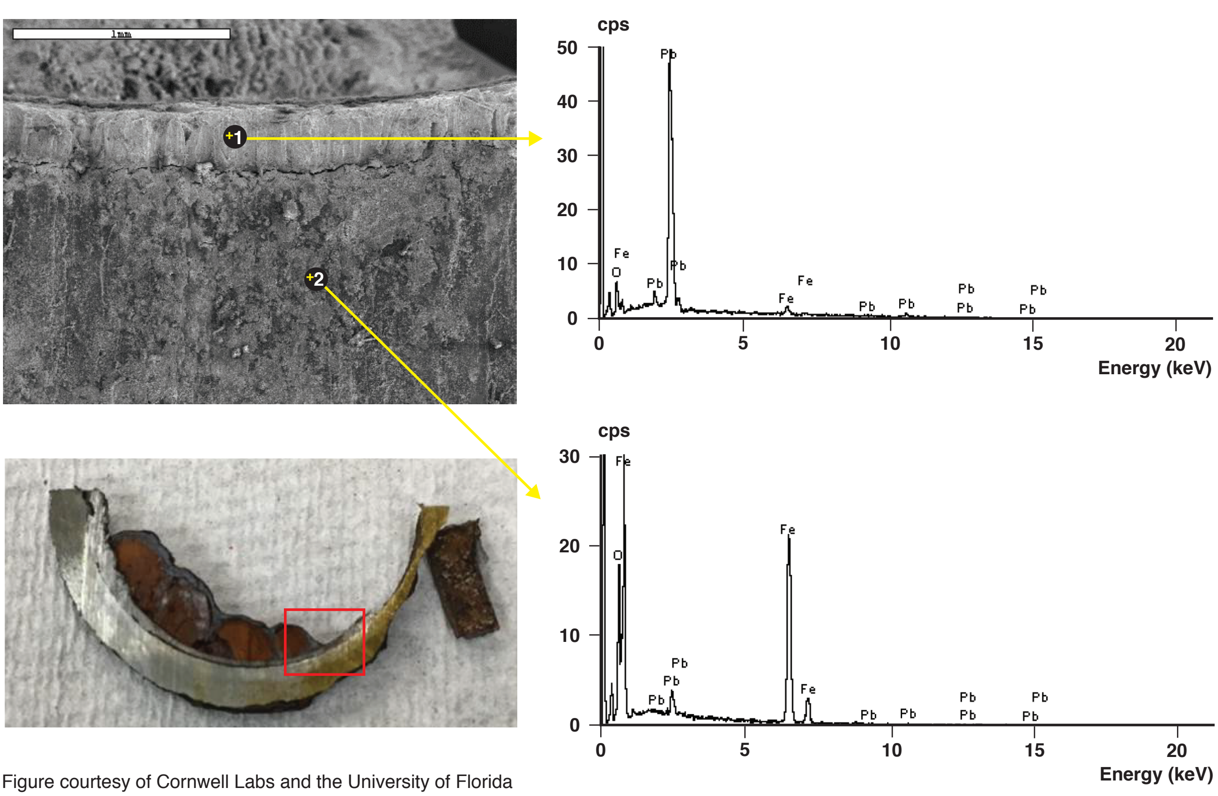


Figure courtesy of Cornwell Labs and the University of Florida

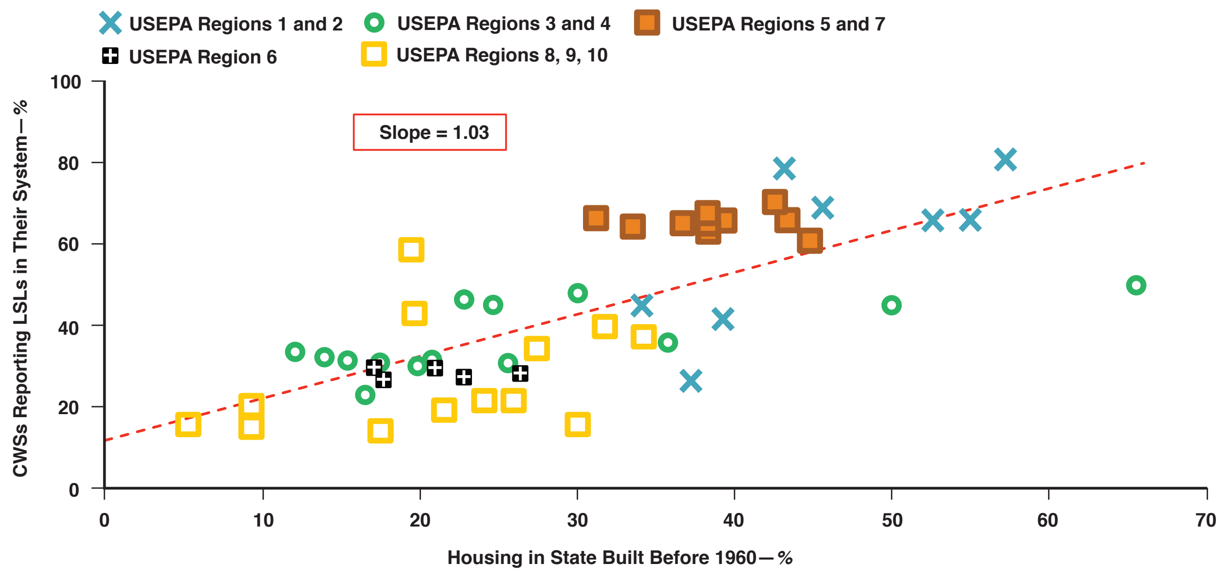
EDS—energy dispersive spectroscopy, Fe—iron, Pb—lead, SEM—scanning electron microscopy

One Perspective on Lead-Lined Pipes a Century Ago

"I am, perhaps, one of those who have had the most experience of anybody in the Association with lead-lined iron pipes. I have been using them for sixteen years, and in perhaps as many as a thousand services. I am very much in favor of making stiff connections, straight, solid connections from the main to the house, and I have yet to have a single one of them break off. The doubt in my mind as to lead-lined pipe was, in the beginning, whether we could get continuous lead lining, and during the early years, the first eight or ten years of our use, I dug up, each year, two or three connections for examination. And the result of those examinations has led me to believe that in almost all of the cases you get a continuous lead lining if you are careful in setting the pipe up properly. . . . And we have not had to renew any of our lead-lined pipes from choking up by rusting or other cause. I have renewed thousands and thousands of both lead and galvanized-iron pipes within the last fifteen years, the life of which has been anywhere from twelve to twenty years. I find that lead pipe is attacked by electrolysis as readily as the iron pipe is and becomes practically rotten and goes to pieces all over."

—Unnamed water utility manager quoted in 1917 *Journal of the New England Water Works Association*

FIGURE 2 Relationship between houses built before 1960 and presence of LSLs



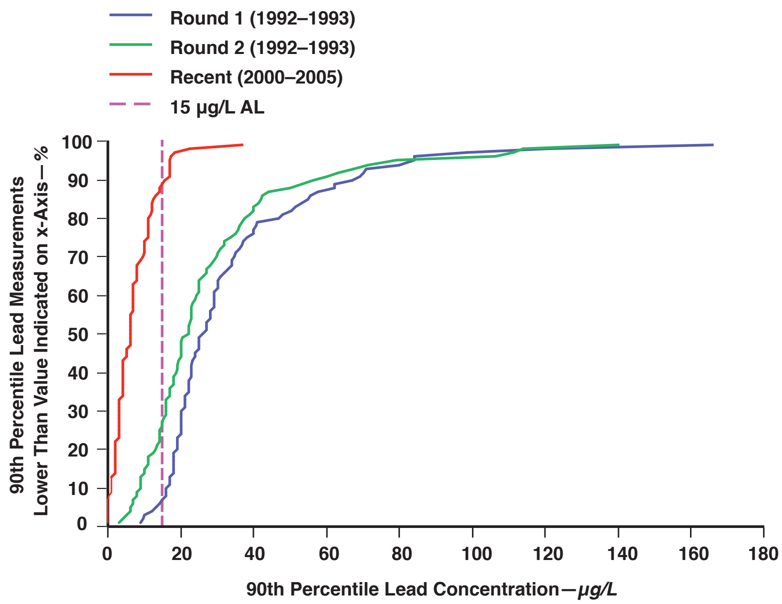
Source: Cornwell et al. 2016

CWS—community water system, LSL—lead service line, USEPA—US Environmental Protection Agency do not have service lines containing lead because of the 1986 SDWA ban on their use. Cornwell et al. (2016) estimated that there are 5.5 million to 7.1 million lead service lines in the United States.

Figure 2 shows the relationship between homes built before 1960 and the percent of utilities by USEPA region that report having lead service lines. It is nearly a 1:1 relationship, suggesting that the age of a state's housing stock could be used as an indicator of the percent of the community water systems in that state that have lead service lines. It may also be useful for a utility to use this approach to estimate the number of potential lead lines in its city. There may be local knowledge to suggest a year other than 1960 would be appropriate for a specific city. Through their lead line survey, Cornwell et al. (2016) also estimated that 15 million to 22 million people in the United States are in homes served with partial or full lead service lines. While that is a significant number, community water systems serve more than 275 million people nationally, and customers with lead lines represent about 10% of the total population served.

Utilities generally responded quickly and effectively to meet the new requirements of the LCR after the regulation's promulgation. Figure 3 shows the 90th percentile lead distribution before and after the LCR for 166 utilities serving over 50,000 persons (Brown et al. 2013). These utilities had 90th percentile lead data above the 15 µg/L action level (AL) before initiating measures to comply with the LCR—so these were the utilities serving more than 50,000 people with the highest lead levels at that time. In 1992–1993, the median of the utilities' 90th percentile lead value was over 20 µg/L and the 90th percentile utility data were over 60 µg/L. Data collected about 10 years later (2000–2005) from the same utilities were examined to determine if, after 10 years of LCR compliance, changes were seen in the lead levels at consumer taps. In 2000–2005, the median lead level for these utilities was 10 µg/L and the 90th percentile was close to the AL. In other words, 90% of these utilities were over the AL in the 1992–1993 sampling, but 10 years later only 10% were over the AL. In Figure 3,

FIGURE 3 Lead distributions in 1992–1993 versus 2000–2005

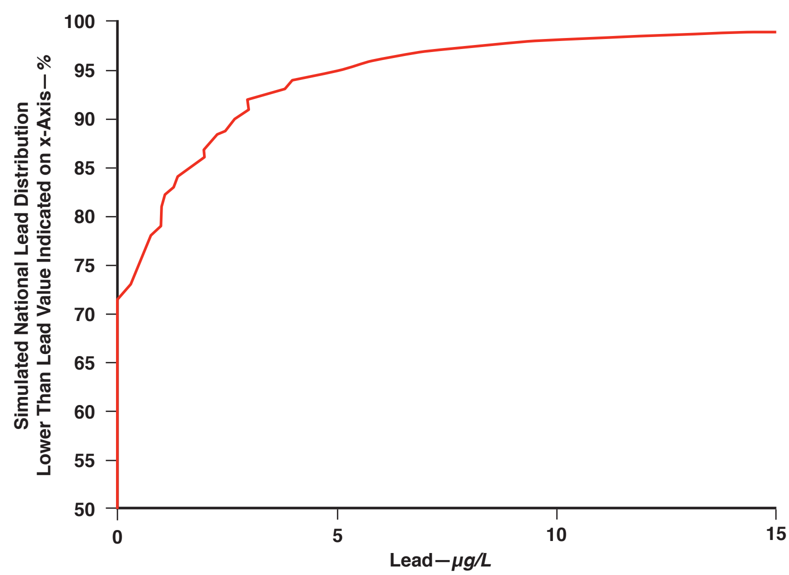


Source: Brown et al. 2013

AL—action level

90th percentile lead data are from facilities serving population >50,000 that exceeded the AL in 1992–1993.

FIGURE 4 Population-weighted US distribution of LCR lead values (2003–2005)



Source: Unpublished research

LCR—Lead and Copper Rule

FIGURE 5 Example of a utility's historical 90th percentile lead levels

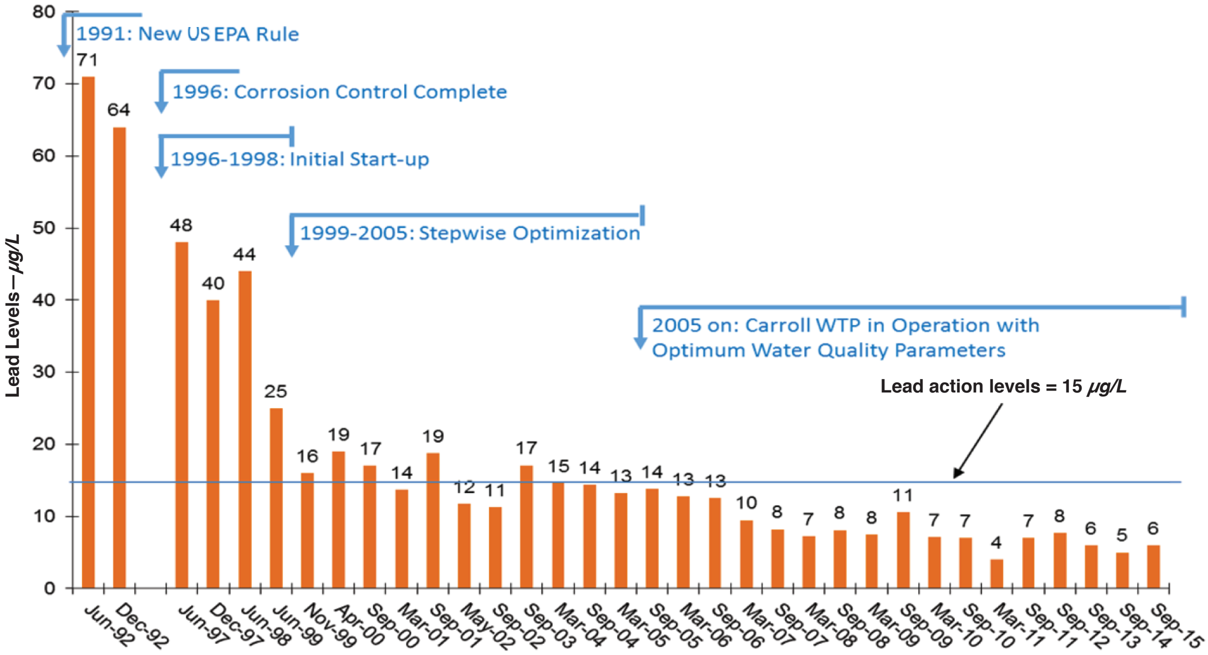


Figure courtesy of Massachusetts Water Resources Authority

USEPA—US Environmental Protection Agency, WTP—water treatment plant

FIGURE 6 Example of a utility's change in lead sample composition 1992–2016

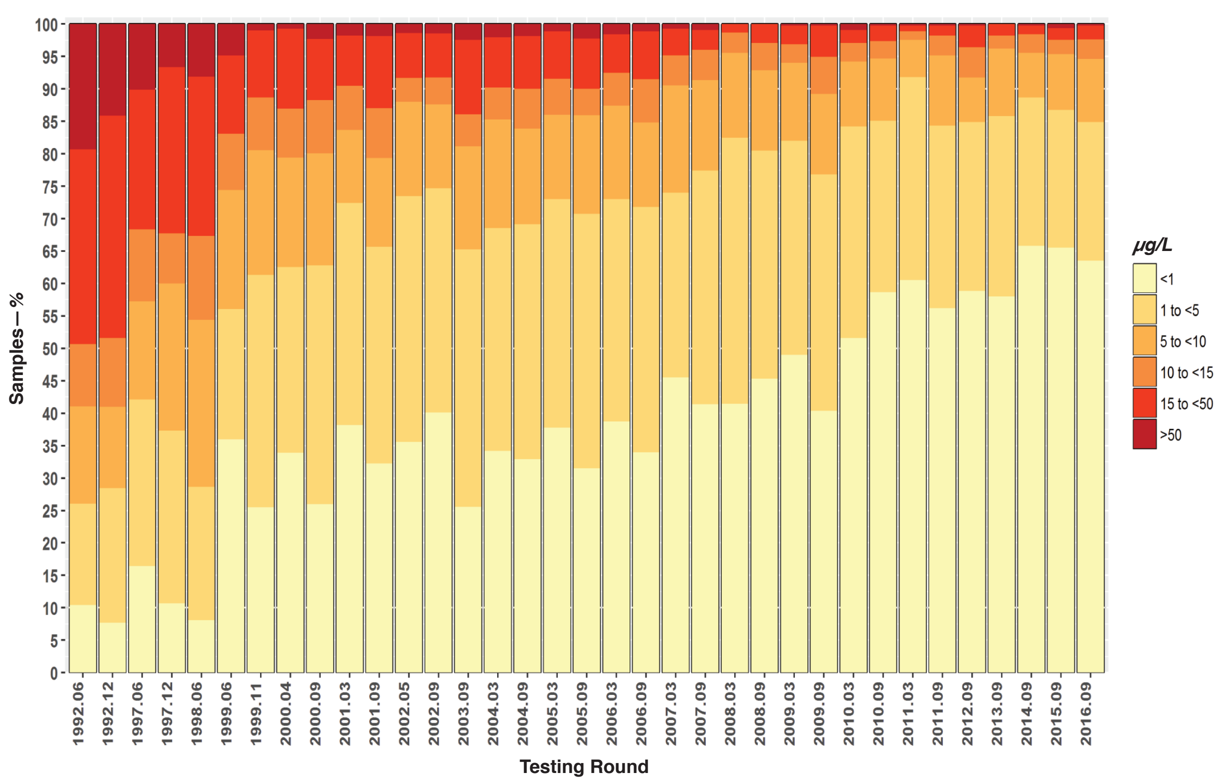


Figure courtesy of Massachusetts Water Resources Authority the reduction in utilities with very high lead levels that occur above the 90th percentile is significant.

PROJECTIONS FOR NATIONAL LEAD DISTRIBUTION

Recently, AWWA provided funding through its Water Industry Technical Action Fund (WITAF) to develop background material on the most current national lead distribution in water at the customer's tap. While this work is in progress, some early projections are available (work being performed by Cornwell Engineering Group and Arcadis). The second six-year review data set (1999–2005) is the latest available national database of full lead data sets collected by utilities. From this database, researchers analyzed 2003–2005 data for systems serving populations greater than 3,300. This working data set has information for 4,300 community water systems (about half of all systems serving a population greater than 3,300 in 2005). Using these data, researchers ran a population-weighted Monte Carlo simulation to develop a national lead distribution. Figure 4 shows the resulting population-weighted national lead distribution for the LCR first-draw sample method in the 2003–2005 data. All the "zero" values are below the detection level, which in 2005 was 5 µg/L for approximately 33% of utilities and 1 µg/L for 33% of utilities. The remaining third of utilities either had detection levels different from these two values, or the detection level was not consistent for all samples.

As shown in Figure 4, in 2003 to 2005 approximately 70% of the population served by community water systems in the United States had a first-draw lead level below the reported detection level. Using these data, it is estimated that less than 5% of the population had first-draw levels above 5 µg/L and less than 1% had a lead level >15 µg/L.

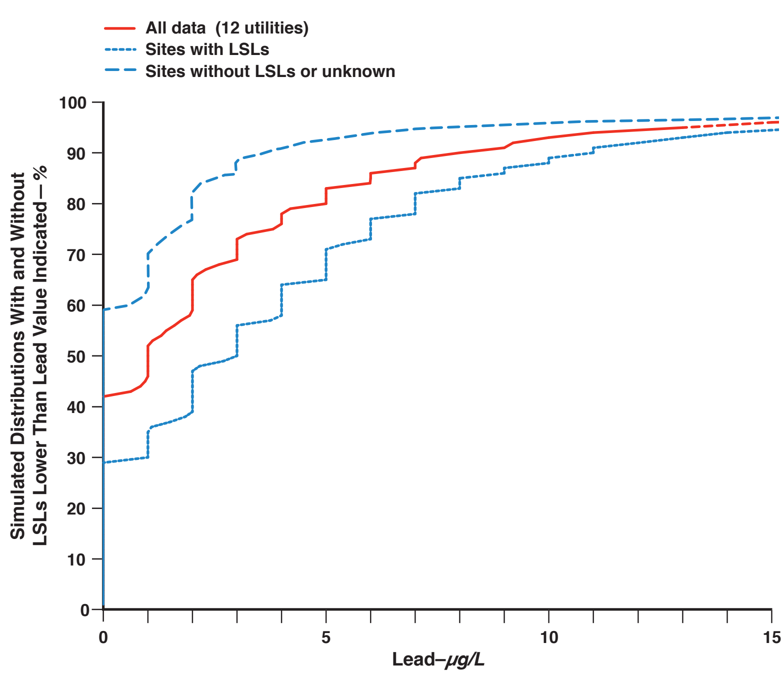
It is also informative to look at the lead sampling history of an individual utility. Figures 5 and 6 show useful ways that utilities can graph their data to see how they have done over the years. This type of information is also useful to post on utilities' websites. Figure 5 is a plot for historical 90th percentile lead data created by Massachusetts Water Resources Authority (MWRA). Figure 5 illustrates the actions taken by the utility in the years since the LCR was enacted as well as the 90th percentile values over the years. As shown, the 90th percentile of lead data for this utility decreased dramatically from over 70 µg/L in 1992 to less than 10 µg/L by 2007.

Figure 6 is a plot of all the lead data from MWRA; it shows the shift in the percent of samples from those with higher levels in earlier years to the current distribution where the majority of samples are less than 1 µg/L. Like many others, this utility has continued to work to lower lead levels in its systems even though they are below the AL.

MORE WAYS FOR UTILITIES TO ANALYZE DATA

Understanding and characterizing distribution system materials, if possible, can provide utilities with an additional way to analyze their data. LCR compliance data were used to produce population-weighted, simulated lead distributions similar to the national lead distribution in Figure 4, but only for 12 participating utilities (Cornwell, unpublished research). Values below the detection limit were assigned a value of zero. Information regarding service line material for each sample was provided in this data set; researchers ran the simulation separately on samples that indicated a lead line was present and on those that did not. As shown in Figure 7, sampling locations with lead service lines have the potential to both increase the lead levels and decrease the number of nondetect samples. The distributions with and without lead lines also show how the distribution

FIGURE 7 Simulated, population-weighted lead distribution for homes with and without LSLs using LCR lead data for 12 utilities



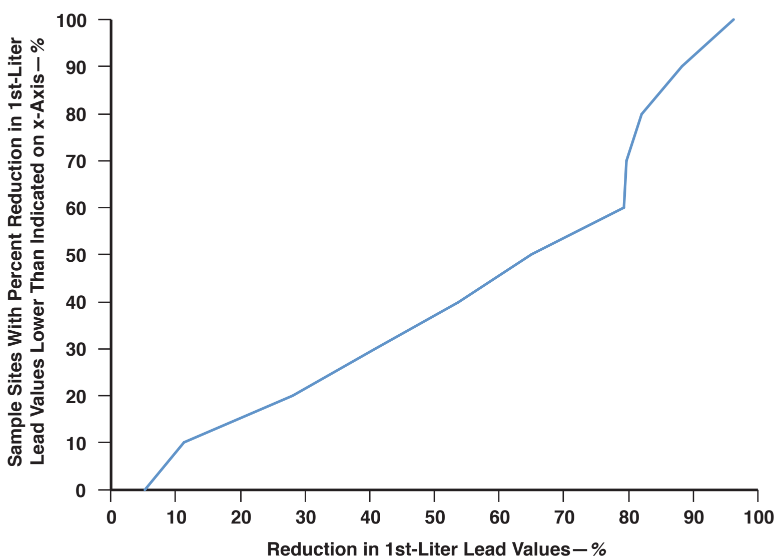
Source: Unpublished research

LCR—Lead and Copper Rule, LSL—lead service line and 90th percentile AL value would change if these utilities removed all their lead lines. In the data in Figure 7, the 90th percentile value for the combined data of homes with and without lead service lines would drop from about 8 μg/L to about 4 μg/L. For homes with lead lines, if the lead lines were replaced, the 90th percentile value for those homes would drop from 11 to 4 μg/L.

Another way to evaluate lead service line impacts is to examine data before and after full lead service line replacement. For 11 homes, first-draw tap samples were collected before lead service line replacement and three months following replacement (Cornwell et al. 2018). In Figure 8, the y-axis is the percent of homes with a lead reduction equal to or less than the x-axis lead reduction. For example, the median (50th percentile) home had a lead reduction of 65%, whereas the 90th percentile home, essentially the best improvement, had a 90% drop in lead level after the service line was replaced. In comparison, the simulation results in Figure 7 show that the median percent decrease by separating out sites with lead lines from those without is approximately 70%. The two approaches, although each with limited data, showed a median lead decrease in the first-liter sample of about 70%. Nationally, lead levels in first-draw samples are relatively low; in fact, about 70% of the population has lead below the defined detection level. Over the 25 years since the LCR, utilities have done a good job in lowering lead levels in water. However, there are cities or areas in cities that may still have high lead values in their water; cities with older homes that have lead service lines are especially vulnerable to higher lead values. Older homes are also more likely to have brass fixtures, galvanized pipe, and copper with lead solder that contain higher levels of lead. These same houses may also be the ones more likely to have lead paint, further increasing the chance of higher lead presence. One challenge, moving forward, is to have better tools to identify more vulnerable cities or areas within cities and to determine the best mitigation measure to reduce overall lead exposure.

> Unfortunately, many utilities did not keep good records of lead service line installations over the years, so it is difficult to know how many lead or lead-lined service lines are still in service.

FIGURE 8 Distribution of the percent reduction in lead levels before lead service line replacement and three months following full service line replacement for 11 houses



Source: Unpublished research

ACKNOWLEDGMENT

National lead distribution data were developed through funding by the AWWA Government Affairs Office through WITAF. All unpublished research cited in this article was funded by AWWA WITAF and is under development.

Steve Estes-Smargassi with MWRA provided Figures 5 and 6. Nancy McTigue provided extensive editing assistance, and Jacob Wagner conducted much of the analysis, including the Monte Carlo modeling; both work at Cornwell Engineering Group.

ABOUT THE AUTHOR

David A. Cornwell (to whom correspondence may be addressed) is president of Cornwell Engineering Group

Inc., 712 Gum Rock Ct., Newport News, VA 23606 USA; dcornwell@cornwell.engineering. He has been a technical advisor to AWWA during negotiations with the USEPA for several regulatory developments affecting US drinking water facilities, including current revisions to the LCR. He is working with AWWA in assessing LCR revision scenarios and is working with many utilities on LCR issues. Cornwell was honored with AWWA's A.P. Black Research Award. He has bachelor's, master's, and doctoral degrees from the University of Florida at Gainesville, where he currently serves as an adjunct professor.

https://doi.org/10.1002/awwa.1167

REFERENCES

Brown, R.A.; McTigue, N.E.; & Cornwell, D.A., 2013. Strategies for Assessing Optimized Corrosion Control Treatment of Lead and Copper. *Journal AWWA*, 105:5:62. https://doi.org/10.5942/jawwa.2013.105.0066.

Clark, B.N.; Masters, S.V.; & Edwards, M.A., 2015. Lead Release to Drinking Water From Galvanized Steel Pipe Coatings. *Environmental Engineering Science*, 32:8:713. https://doi.org/10.1089/ees.2015.0073.

Cornwell, D.A.; Brown, R.A.; & Schmelling, M., 2018. *Evaluation of Flushing to Reduce Lead Levels.* Project #4584. Water Research Foundation, Denver.

Cornwell, D.A.; Brown, R.A.; & Via, S.H., 2016. National Survey of Lead Service Line Occurrence. *Journal AWWA*, 108:4:E182. https://doi.org/10.5942/jawwa.2016.108.0086.

NEWWA (New England Water Works Association), 1917. Report of the Committee on Service Pipes. *New England Water Works Association Journal*, 31:3.

USEPA (US Environmental Protection Agency), 1991. Drinking Water Regulations. 40 CFR Parts 141 and 142. *Federal Register*, 56:110:26460.

AWWA RESOURCES

- A Progress Report on Efforts to Address Lead by Public School Districts. Sanborn, L.H. & Carpenter, A.T., 2018. *Journal AWWA*, 110:3:E18. https://doi.org/10.1002/awwa.1022.
- Fine-Tune System Operations for Lead and Copper Rule Compliance. Ghosh, A., 2018. *Opflow*, 44:2:24. https://doi.org/10.5991/OPF.2018.44.0016.
- Evaluate Lead Service Line Lining and Coating Technologies. Cuppett, J. & Randtke, S.J., 2017. *Opflow*, 43:10:10. https://doi.org/10.5991/OPF.2017.43.0062.

These resources have been supplied by *Journal AWWA* staff. For information on these and other AWWA resources, visit www.awwa.org.