High-Velocity Household and Service Line Flushing Following LSL Replacement

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Customer exposure to lead solely from drinking water may be greater in water containing particles than in water containing only soluble lead. Full and partial lead service line (LSL) replacements and other similar disturbances can potentially increase the release of lead-containing particulates. Lead-containing particles, loose scale, and other debris that can otherwise be transported to the customer tap can be removed by preventive measures like home water filters. This study investigated the use of high-velocity flushing to preemptively dislodge and remove particulate lead following partial LSL replacements in order to at least reduce, and hopefully eliminate, the particles of lead reaching the consumer. Results suggest a potential benefit to flushing the service line and premise plumbing by opening taps inside the house but not from solely flushing the service line by opening hose bibs.

Keywords: *corrosion, flushing, lead, Lead and Copper Rule, particulate metals, regulatory compliance*

The research summarized in this article describes an investigation of high-velocity flushing following replacement of the utility-owned portion of the lead service line (LSL). In all cases during this study, the "utility side" of the service line was originally lead. At one utility the "customer side" was confirmed to be galvanized iron (as expected), a second utility participant expected to find lead but instead found copper, and the third participant expected to find lead at all locations but instead found copper or polyethylene at one-third of the study locations. The study included a comparison of flushing at an outside hose bib versus adding a step to also flush the household plumbing by opening all taps (wide open, screens/aerators removed) to dislodge and remove particles from the premise plumbing as well as from the service line.

Figure 1 is representative of the site conditions commonly encountered in many water systems where the meter is located inside the house in colder climates and outside the house in warmer climates (though other configurations are possible). In this study, the utility side of the service line ("L1" in Figure 1) was replaced with copper.

BACKGROUND

Partial LSL replacement (i.e., replacement of the utility portion of the service line while keeping the original customer side in place) has the potential to increase lead release, especially from the release of particulate lead. During replacement of the LSL, the associated lead scale remains in the customer side of the service line and in the premise plumbing. These scales are disturbed after partial LSL replacement and can become dislodged. Even full LSL replacement (utility and customer portions of the service line) can create vibration and other disturbances that could cause dislodgement and release of scale and other particulate matter inside the premise plumbing and appurtenances. Experience with LSL replacement, especially partial replacements, has indicated that it can take several months after the disturbance for the lead releases to be reduced to acceptable levels, chiefly because of sporadic releases of particulate lead (DC Water, 2013; Providence Water, 2013; USEPA, 2011).

Water with particulates containing lead or with lead sorbed onto them has the potential to expose customers to higher lead concentrations than soluble lead dissolved in the bulk water phase (Clark et al, 2014; McFadden et al, 2011; Deshommes et al, 2010; Triantafyllidou et al, 2007; McNeill and Edwards, 2004). Because this particle release is an intermittent process perhaps associated with higher faucet flows, it is difficult to predict or monitor. Nonetheless, it can be shown that higher pipe velocities can mobilize more particulate matter present than at lower rates (Clark et al, 2014; Cartier et al, 2012; Triantafyllidou and Edwards, 2012).

Two approaches to reduce the potential consequences of particulate lead release after a partial LSL replacement are to (1) periodically dislodge and remove "loose" particles and scale by flushing the lines or (2) use a home water filter (an NSF/ANSI Standard 53 device certified for lead) for direct drinking water consumption such as drinking water, baby formula, cooking, and dental care. (Some Standard 53–certified products are not certified for lead but are certified for other particulate material. Standard 53–certified products suitable for lead removal must explicitly identify lead as one of the contaminants removed. If the product is certified, it means that the product does not contain lead or release lead from its components, plus it removes particulate and soluble lead from water.)

These alternative approaches are not mutually exclusive. Therefore, a customer with a home water filter would still benefit from periodic dislodgement and removal of particulate material via high-velocity flushing as described in this article.

Previous research has documented the problem associated with lead release after partial LSL replacement, as noted in the Sept. 28, 2011, Science Advisory Board (SAB) report (USEPA, 2011) and references cited within (e.g., Sandvig et al, 2008). Numerous sources confirm that low-velocity displacement flushing the night before sampling, even for as little as 10 min, can reduce the lead concentration in samples collected the following morning (Cantor, 2010; Triantafyllidou et al, 2009; Murphy, 1993; and others), though high lead levels return if this type of flushing is not repeated before sampling on subsequent days. Murphy (1993) found that 10 min of flushing reduced lead levels by about 50%. These flushing studies were conducted at low velocity, and were intended to displace stagnant water, as opposed to the higher-velocity conditions analogous to unidirectional flushing in the distribution system needed to dislodge and remove particulate deposits.

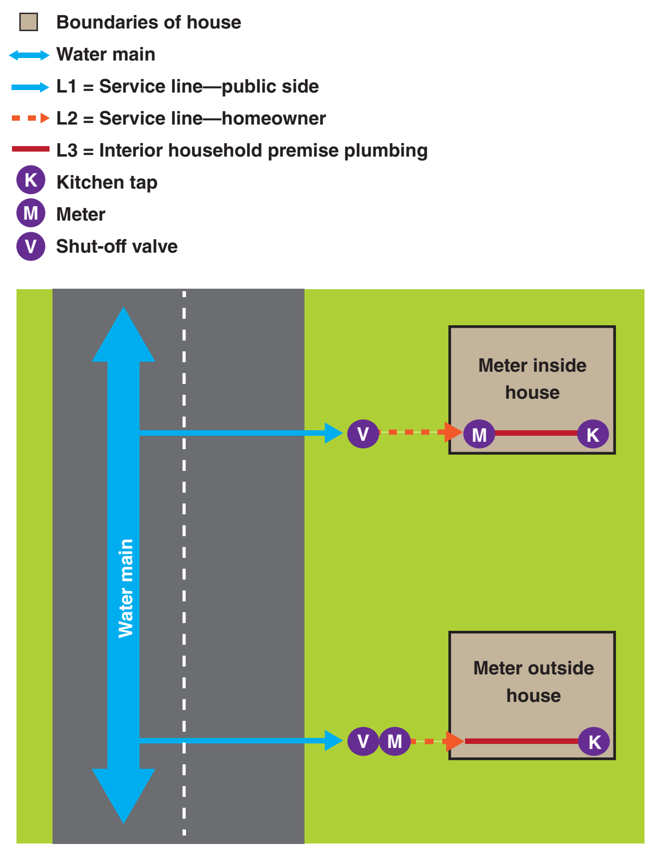
Consequently, it is established that low-velocity flushing can have short-term effects on the removal of lead and other particulates, but limited work has been reported evaluating more rigorous flushing practices to produce additional benefits. Boyd et al (2004) reported lead levels equilibrating at < 10 µg/L after about a week of low-velocity flushing following simulated LSL replacement in laboratory studies. Under intermittent conditions (including stagnation periods), there was no improvement within the first two weeks. These results suggest that even low flushing rates can accelerate the return to stable conditions after partial LSL replacement, and that higher flow rates may further accelerate remediation.

Sandvig et al (2008) cited information from a survey of drinking water and public school system participants indicating that flushing after partial LSL replacement (< 8.3 L/min or < 2.2 gpm) improved lead levels, though in some cases a short duration of flushing at this low flow rate may not have been enough. For example, 15 min or less of flushing was shown to have a positive effect in some cases but not in others.

Laboratory studies reported in Raetz (2010) investigated the impact of flushing on the removal of metallic debris (e.g., debris from construction/installation) and soldering flux. Water-soluble flux products (i.e., ASTM B813–compliant) were removed after 30 min at 3 ft/s (0.9 m/s), though in one instance 2 h of flushing at this velocity was needed to remove flux from bends and joints. Petroleum-based flux (i.e., not ASTM B813–compliant) was more persistent, with about 80% remaining after flushing for 20 h at 3 ft/s (0.9 m/s) and 50% after 6 h at 7 ft/s (2.1 m/s). Experiments with added metallic debris, simulating debris remaining after cutting, sanding, and otherwise manipulating pipe materials, showed that 90% of the debris added was removed within about 5 s at 4.2 ft/s (1.3 m/s) when placed in straight pipe before upward 90° bend.

In comments to the SAB, Edwards (2011) provided an example demonstrating that the particulate lead concentration increased at a given tap location as the sampling velocity increased from < 2 L/min to about 21 L/min (7 gpm). At the highest rate, the particulate lead level was still increasing, but the trend of these data suggests that the particulate lead release would level off at some rate greater than 21 L/min. The purpose of the data presented by Edwards (2011) was to demonstrate that higher sampling velocities may be needed to mobilize some of the particulate lead that may be present. However, these data also suggest that it may be possible to determine a maximum flushing velocity above which little additional release of particulate lead will occur.

FIGURE 1 Schematic of two common configurations for service line connecting utility-owned water main to a customer's house*



*Meter inside the house in cold climates versus outside the house in warmer climates

PROJECT DESCRIPTION

Objectives/plans. The project was funded by AWWA (Water Industry Technical Action Fund [WITAF] Project 306), targeting an investigation into the benefits, if any, of high-velocity flushing following partial LSL replacement. Most utilities perform a flush of the service line, typically at least 10 min, by flushing the newly installed pipe via the hose bibs. All locations in this study completed at least a 10-min flush in this manner. This study included an evaluation of two alternative flushing mechanisms to see whether they improved subsequent household lead levels versus the "normal" 10-min outdoor flush described earlier.

The study compares a 10-min outdoor flush with two additional flushing methods: (1) flushing the outside hose bibs for 20 min instead of 10 min following LSL replacement and (2) 10 min of flushing by the water system outside the house using hose bibs followed by flushing from inside the house with the customer opening all indoor household taps for 30 min. Participating utilities were not asked to change their normal LSL replacement practices other than adding flushing steps and postflushing sampling steps.

Flushing types. Water systems were asked to perform three kinds of flushing later in the day after the LSL was replaced. A 10-min flush at the hose bib outside the house was referred to as "10-min outside" and labeled with an "A." As discussed, this was considered normal practice of the participating utilities and was used as a baseline for comparison of the more rigorous methods. At locations labeled "B," there was an identical flush of the service line from outside the house, except the duration was 20 min instead of 10 min. Locations labeled with a "C" were also flushed for 10 min outside the house, then customers at these locations opened all indoor taps (wide open, highest velocity), with aerators and screens removed, for 30 min. All utility participants were able to include examples of each of these types of flushing. Flushing was conducted the day of the replacement, and then samples were collected the next morning after the water inside the house remained stagnant overnight for at least 6 h. Subsequent samples on later dates were also collected after stagnation. One utility collected samples before the LSL replacement.

Flushing outside the house was performed solely by water utility staff or their authorized vendors without involvement of the customer (except for sample collection using utility supplied protocols). For flushing inside the house, the customer was given instructions for both flushing and sampling, and asked to perform flushing (opening taps) on the day of the LSL replacement and sampling tasks on subsequent dates as instructed.

Sample collection and analysis. All samples were collected by the customers using directions (protocols) and sample containers provided by the water system. Customers were instructed to collect samples as quickly as possible (i.e., with the tap wide open) with screens and aerators removed.

The sampling protocol summarized in Table 1 consisted of five sequential samples collected from the customer tap after remaining stagnant overnight. The first sample collected was an initial 500 mL (0.13 gal) from the tap (similar to the current Lead and Copper Rule [LCR] "first flush" compliance sample), then a 1-gal sample (3.785 L), another 500 mL, another 1 gal, and a final 500-mL sample. All the 500-mL samples were analyzed, but the 1-gal samples were collected by the customers and returned to the utility but not analyzed. Therefore, the three 500-mL samples that were analyzed represent roughly the 0–0.5 L (0–0.13 gal), 4.3–4.8 L (1.13–1.26 gal), and 8.6–9.1 L (2.26–2.40 gal) from the tap. These samples are referred to as the 0.5-L, 4.5-L, and 9-L samples.

TABLE 1 Summary of sampling sequence at each location during the study

Description	Volume *L*		Analyzed for Total Lead
	Individual Sample	Cumulative	
Initial 0.5 L	0.500	0.500	Yes
1 gal	3.785	4.285	No
0.5 L at ~ 4.5 L	0.500	4.785	Yes
1 gal	3.785	8.570	No
0.5 L at ~ 9 L	0.500	9.070	Yes

Each water system analyzed and reported all results using identical procedures as during LCR compliance sampling (except for sample bottle volume), including analysis of metals (i.e., acidified/preserved bottles) using Standard Method 3113B or equivalent (*Standard Methods*, 2012).

PROJECT FINDINGS

Studies were conducted at three water systems, each providing water to > 100,000 people. The source water, treatment, and other characteristics of the three water systems studied are summarized in Table 2.

Utility X. This utility provides treated water using a river and a reservoir for source water, conventional treatment with alum coagulation, chlorine dioxide and chloramine as disinfectants, and orthophosphate as a corrosion-control inhibitor. The finished water pH is ~ 8.3, alkalinity ~ 30 mg/L as calcium carbonate

TABLE 2 Summary of source water, treatment, and other characteristics of participating utilities

Characteristics	Utility X	Utility N	Utility P
Source water	Surface water	Surface water	Groundwater
Treatment	Alum coagulation	Alum coagulation	Lime softening
Primary Disinfectant	Chlorine dioxide	Free chlorine	Free chlorine
Residual Disinfectant	Chloramines	Chloramines	Free chlorine
pH	8.3	7.6	8.6
Alkalinity—*mg/L as* $CaCO_3$	30	35	75
Orthophosphate—*mg/L as P*	0.4	0.5	Not added
90th percentile lead*—*mg/L*	0.0023	0.005	< 0.003

$CaCO_3$—calcium carbonate, P—phosphorus

*Most recent compliance period

($CaCO_3$), and an orthophosphate finished-water target residual of 1.2 mg/L as phosphate (PO_4) (0.4 mg/L as phosphorus [P]). The most recent lead compliance results revealed a 90th-percentile value of 0.0023 mg/L.

Figures 2, 3, and 4 depict results following replacements at 10 houses: four flushing for 10 min outside the house (A), two flushing for 20 min outside the house (B), and four flushing outside the house for 10 min then 30 min inside the house (C). All of the replaced LSLs were 3 to 6 ft long (the utility side of the service line between the water main and household water meter at the start of the customer-owned portion of the service line), as summarized in Table 3. The utility replaced all of the lead line on its side of the meter. The customer side of the service line was copper. Figure 2 shows the results for the samples collected the day after LSL replacement. Figure 3 includes data for samples collected one month after replacement (note that results from one "A" location were not reported), and results in Figure 4 from one month after that (i.e., two months after replacement). The following observations were made from these results:

- Only two individual results were above the 0.015 mg/L action level.
- Results from all locations were generally lower two months after replacement (Figure 4) than on the day after replacement (Figure 2).
- There was no apparent difference between the two methods of flushing outside the house (A and B locations). However, flushing inside the house (C locations) produced lower lead levels, essentially below the detection limit (0.001 mg/L), after one month.

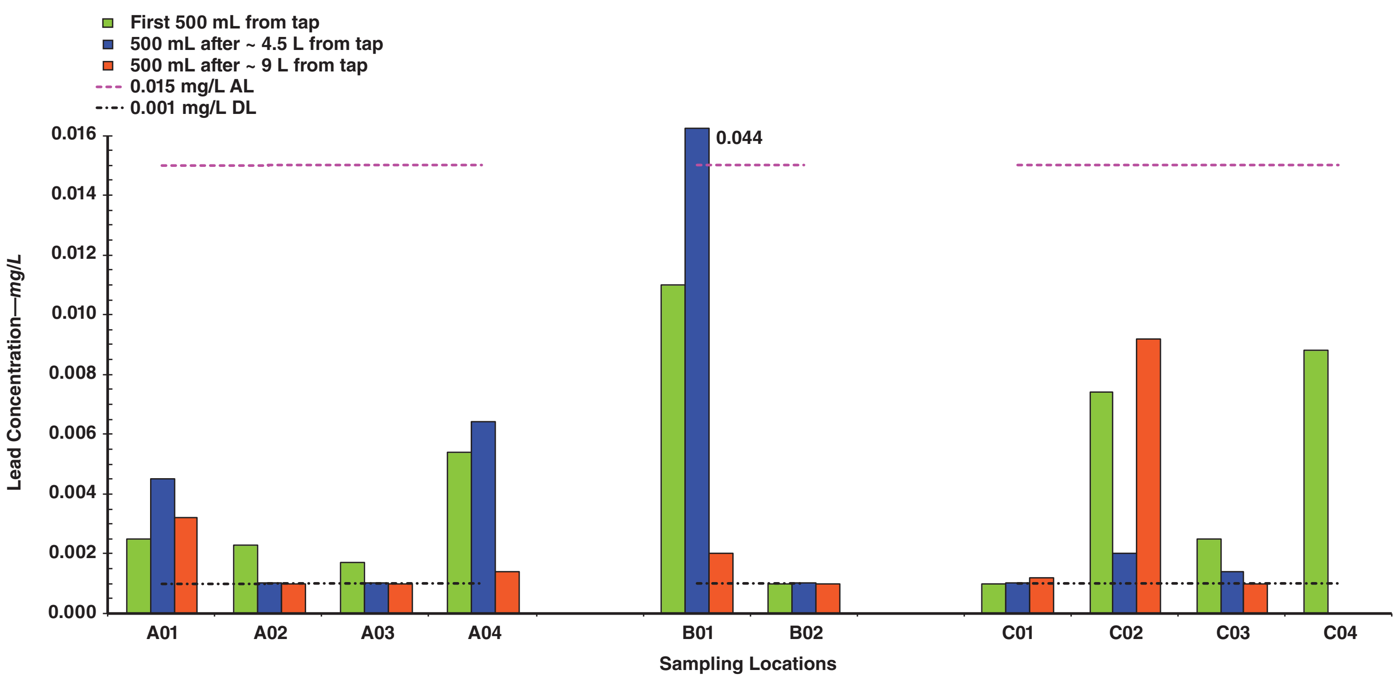
TABLE 3 LSL replacements for study locations at utility X

Location	Diameter *in.*	Length of Utility Service Line Replaced *ft*
	10-min outdoor flush	
A01	¾	4
A02	1	5
A03	¾	4
A04	¾	3
	20-min outdoor flush	
B01	¾	3
B02	¾	6
	Indoor plus 10-min outdoor flush	
C01	¾	3
C02	¾	3
C03	¾	4
C04	¾	4

LSL—lead service line

- Of the 28 sampling events depicted in Figures 2, 3, and 4, there were 15 times when all three results in the group were essentially < 0.001 mg/L detection limit, five times when the 0.5-L result was the highest, five times when the 4.5-L result was the highest, and three times when the 9-L sample result was the

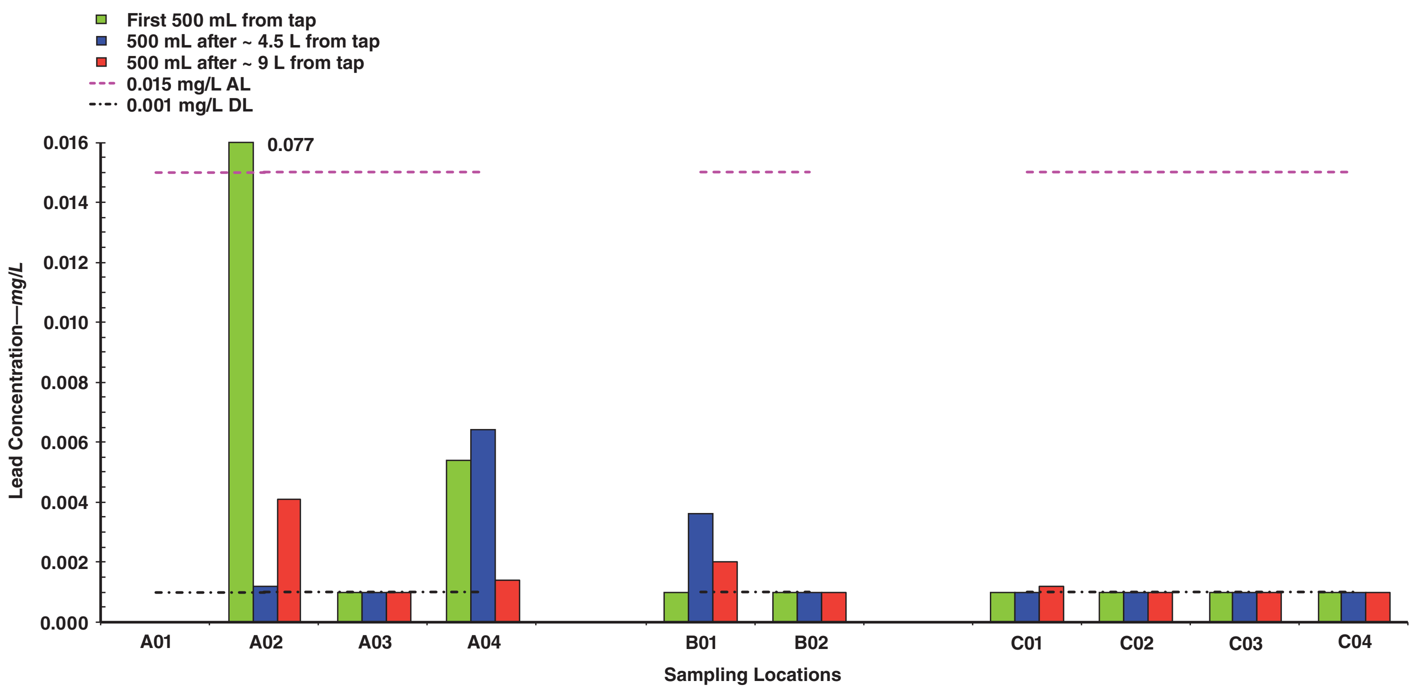
FIGURE 2 Utility X—samples collected on the first day after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

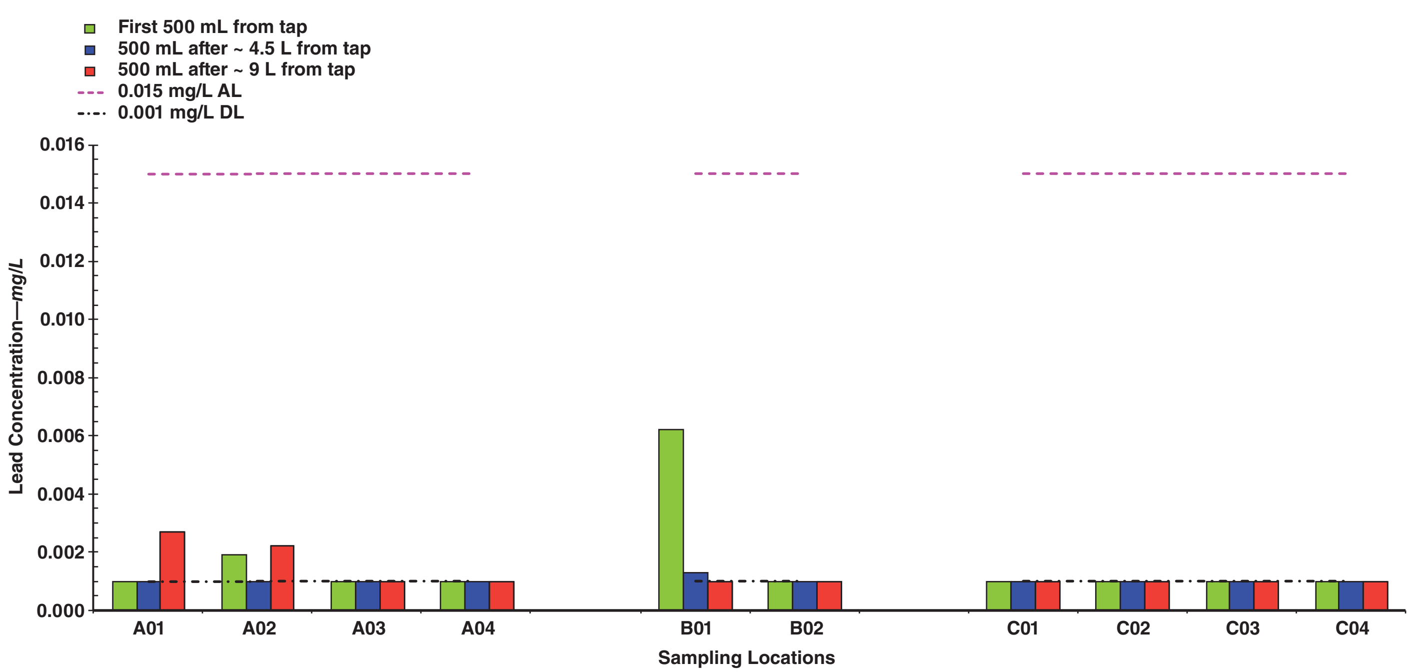
FIGURE 3 Utility X—samples collected one month after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

FIGURE 4 Utility X—samples collected two months after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

highest. Therefore, multiple samples were needed to detect the peak lead level, not just a single first-flush sample, 4.5-L sample from LSL, or any other single sample.

- During the first month, the peak lead occurred in the same profile volume as on the first day, but in the second month the peak was in a different profile volume than on the first day.
  - For locations with at least one detectable lead sample in both the first-day and first-month samples, the peak occurred in the same profile volume (initial 0.5 L for A02, 4.5 L for A04 and B01, and 9 L for B02). Location A01 was not sampled in the first month (see the next item).
  - For locations with at least one detectable lead sample in both the first-day and second-month samples, the peak occurred in a different profile volume (all occurred in the 4.5-L sample on the first day, but in the second month, it was 9 L for A01 and A02, and the initial 0.5 L for B01).

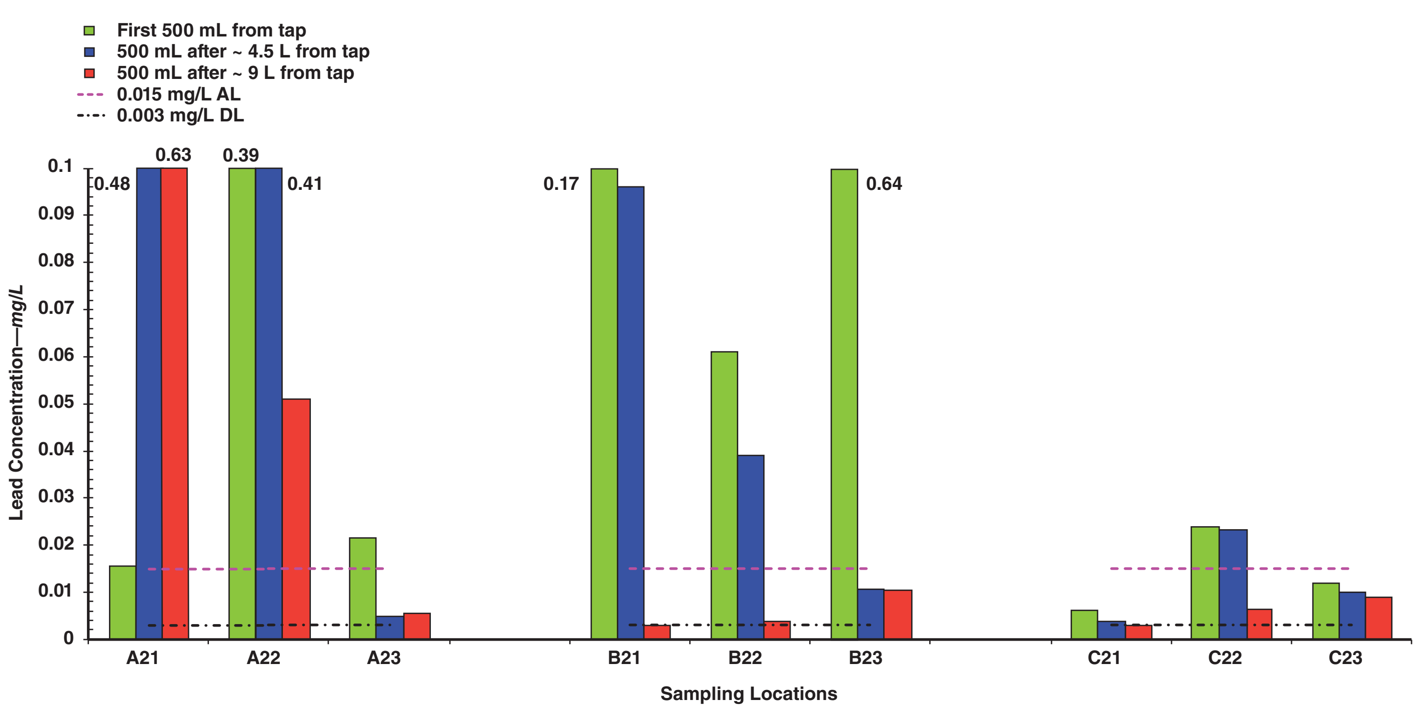
Therefore, at the locations studied in this water system, flushing all plumbing from inside the house at a high velocity showed more improvement in reducing lead levels than either a 10-min or 20-min flush at the outside hose bib. These results suggest that the lead-containing particles were located in the premise plumbing itself at the homes studied, and that it may be possible to use the indoor high-velocity flushing to remove the particulate material and reduce customer exposure to lead.

Utility P. This utility provides treated water using groundwater sources, softening and recarbonation (no coagulant) to remove hardness, free chlorine as the primary disinfectant and residual disinfectant, and no corrosion inhibitor. Finished water pH is ~ 8.6, alkalinity ~ 75 mg/L as $CaCO_3$, and conductivity ~ 480 µmhos/cm. The most recent lead compliance results indicate a 90th percentile lead of < 0.003 mg/L.

Figures 5, 6, and 7 depict results following replacements from the water main to the curb stop at the property line at nine houses located in a three-block area where a water main replacement was completed. Table 4 summarizes the LSL replacements for this water system. All replacements on the utility side were completed using 1-in. diameter copper. All service lines on the customer side were galvanized iron. The utility identified three locations for each of the three types of flushing. Figure 5 shows results for the samples collected the day after LSL replacement, Figure 6 shows results from one month after replacement, and Figure 7 one month after that (i.e., two months after replacement). Note that four customers did not collect the requested samples during the last sampling period (Figure 7). The following observations were made from these results:

- The lead results at utility P (Figure 5) were higher than at utility X (Figure 2) on the first day after LSL replacement, but after the first month, the results at the two utilities were similar.
- In the samples collected the first day after replacement at utility P (Figure 5), the lead was lower in the samples flushed inside the house (C) than at locations flushed at the hose bib (A and B).
- The lead results seemed to improve in the first and second months. Location B21 improved after the first month (compare Figures 5 and 6) but remained about the same in the second month (compare similar results in Figures 6 and 7). All other locations

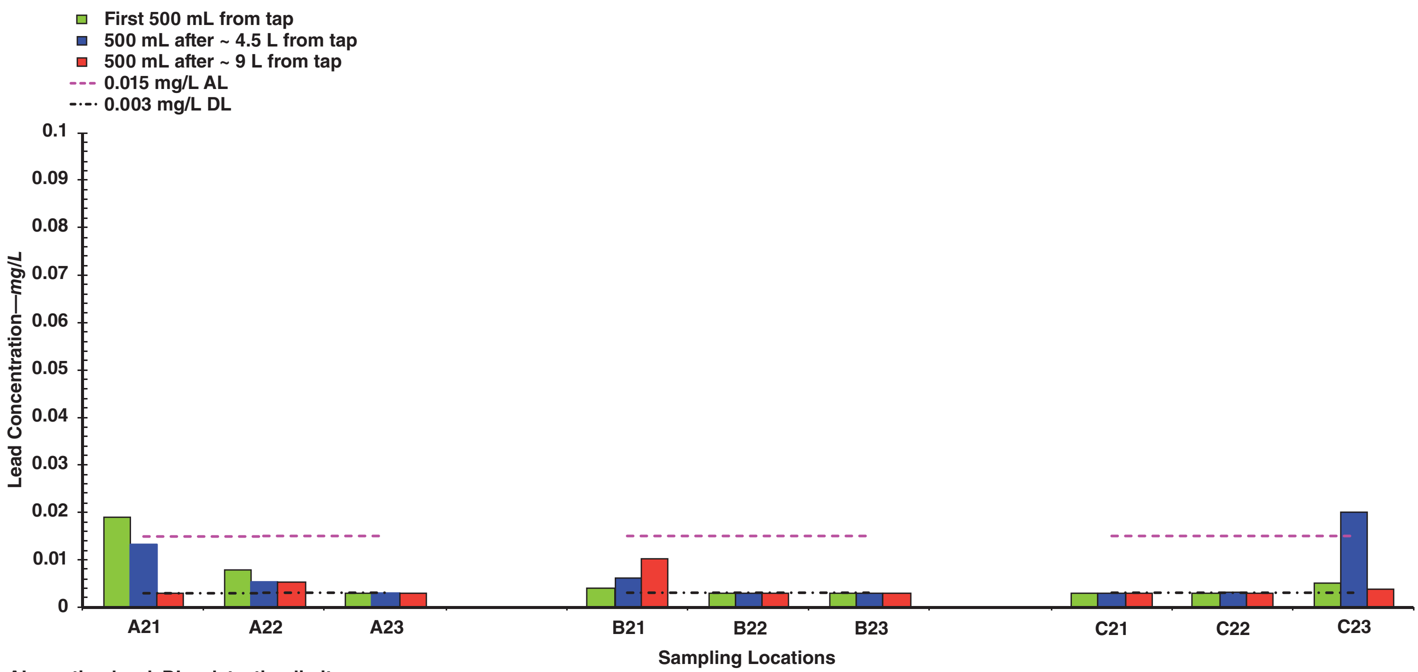
FIGURE 5 Utility P—samples collected on the first day after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

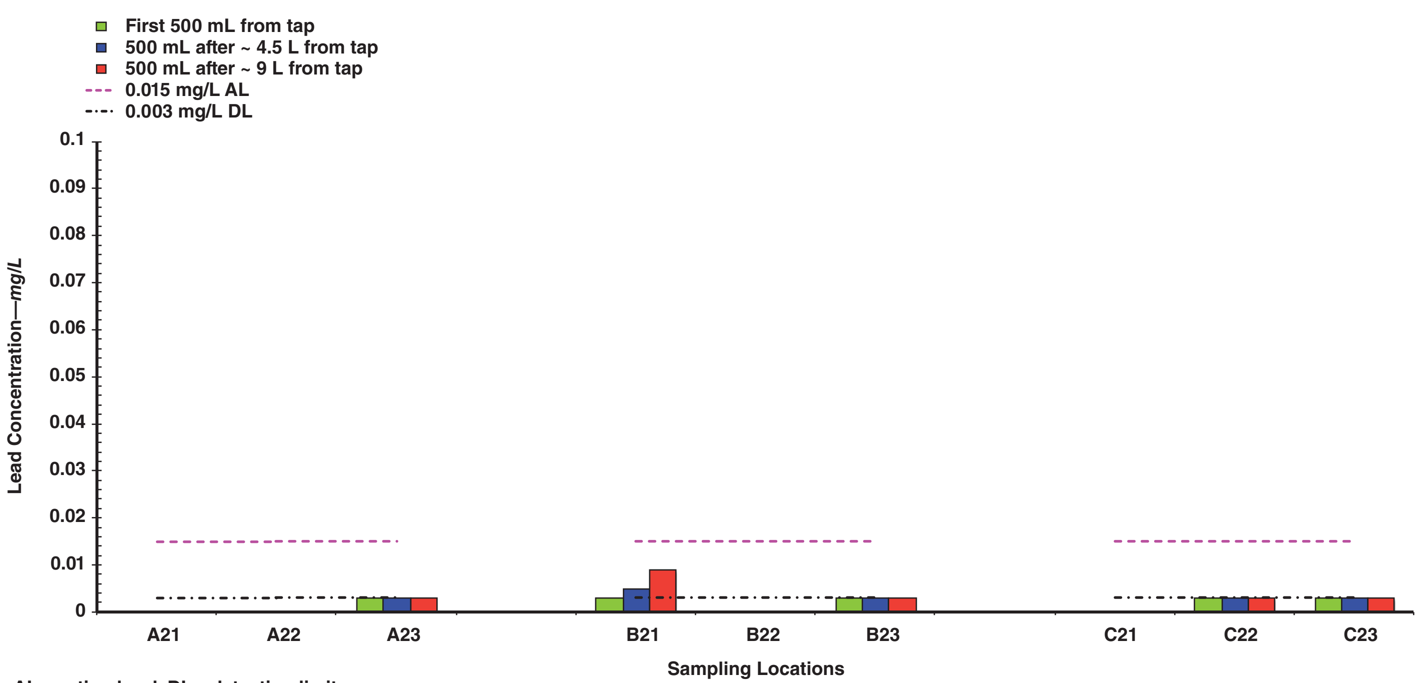
FIGURE 6 Utility P—samples collected one month after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

FIGURE 7 Utility P—samples collected two months after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

TABLE 4 LSL replacements for study locations at utility P

Location	Length of Utility Service Line Replaced *ft*
10-min outdoor flush	
A21	11
A22	26
A23	28
20-min outdoor flush	
B21	25
B22	26
B23	8
10-min outdoor flush plus 30-min indoor flush	
C21	11
C22	10
C23	8

LSL—lead service line

sampled during the second month either remained below the detection limit or improved to below the detection limit.

- At locations flushed inside the house, peak lead levels improved to below the detection limit after one month (C21 and C22) or two months (C23).
- There may not have been much difference between results collected at locations with 10 (A) or 20 min (B) of only outdoor flushing, although it is difficult to be more definite because half of these locations were not sampled during the second month. Three of the locations that flushed only outside the house had at least one lead sample above the detection limit after the first month (A21, A22, B21), and one had detectable lead after the second month (B21). By contrast, all locations flushed inside the house were below the detection limit by the second month.
- There was no evidence that the peak lead occurred in the same profile volume in each of the three sample dates, but this could be due to the limited number of sample locations, the occurrence of results below detection limit after the first day, and uncollected samples at some locations in the second month, as summarized below:
  - At five locations, the peak lead occurred in the initial 0.5 L on the first day but was undetected on subsequent dates.
  - At three locations, the peak lead occurred at a different profile volume on the first day compared with the first month.
  - At one location, the peak lead occurred in the initial 0.5 L on both the first day and first month, but the second-month samples were not collected.
- The C23 result for the one-month sample was the only case in which the 4.5-L sample was the highest (for locations with at least one profile sample above the detection limit). However, although the 0.5-L result was typically the highest, the 4.5-L result was often only slightly lower. For example, of the 15 samples above the 0.015 mg/L action level (Figures 5, 6, and 7), seven were 0.5-L samples and six were 4.5-L samples.

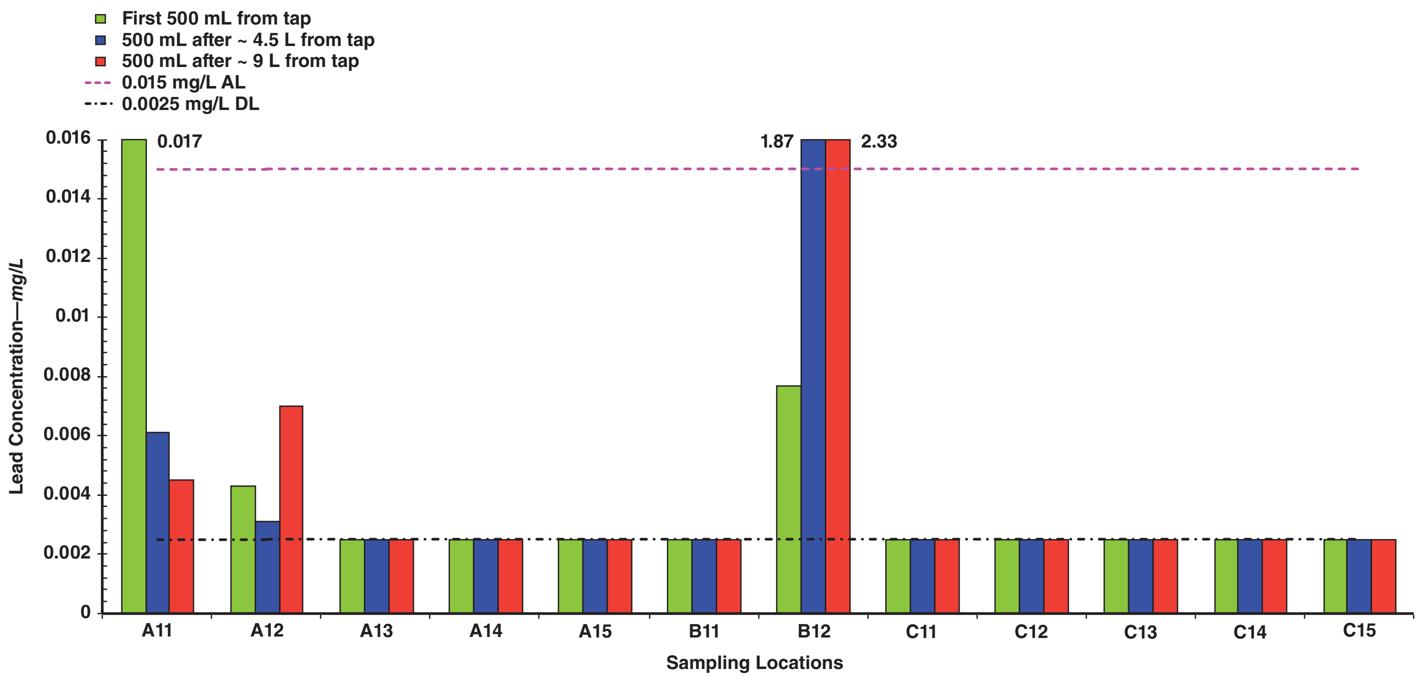
There is some evidence that flushing inside the house (C locations) produced lower lead levels than flushing only from outside the house (A and B) at locations studied at this utility. However, missing results from customers who did not collect samples in the second month and one result at C23 above the 0.015 action level in the first month make it difficult to make a more conclusive, definitive statement regarding a demonstrated impact of flushing inside the house, using data from this utility.

Utility N. This utility provides treated water using a river source, conventional treatment with alum coagulation, chloramine as the residual disinfectant, and orthophosphate as a corrosion-control inhibitor. The finished water pH is about 7.6, alkalinity ~ 35 mg/L as $CaCO_3$, and an orthophosphate finished-water target level of 1.5 mg/L as PO_4 (0.5 mg/L as P). The most recent lead compliance results revealed a 90th percentile value of 0.005 mg/L.

Figures 8 and 9 depict results following replacements at 12 houses: five flushed for 10 min outside the house (A), two flushed for 20 min outside the house (B), and five flushed by the customer inside the house after the utility staff flushed the service line outside the house for 10 min (C). Table 5 lists the length of LSL replaced on the utility side (between the water main and meter at the property line) at each location along with a description of the material on the customer side of the service line after the meter. This utility volunteered to analyze samples collected by the customers on the day before the LSL replacement. Like the others, customers at this utility collected samples on the first day after replacement and flushing, but unlike others, they did not collect any samples in later months. Figure 8 summarizes the results before replacement, and Figure 9 summarizes results on the first day after replacement and flushing. The following observations were made from these results:

- At all three utilities studied, the highest lead was observed the first day after the LSL replacement and flushing. In the other two utilities, there was improvement within the first one or two months. Therefore, it is possible that similar improvement may have occurred at utility N, but the samples to confirm this were not collected. This was apparently due to the complexity of the sample-collection procedures and the unwillingness of utility staff and customer volunteers to collect samples on later dates.
- With the limited data there were mixed results on improvement by flushing. One day after the LSL replacement and flushing, the lead levels improved at two locations (A11 and B12—but the latter was still above the 0.015-mg/L action level). At five locations, the lead level went from below the detection limit before the LSL replacement to detectable lead levels in at least one profile sample (A14, C11, and C15 below 0.015 mg/L and A12 and C12 above the action level) the next day. At five locations, the lead value remained below the 0.025 mg/L detection limit in both sampling events (A13, A15, B11, C13, and C14).
- For locations with at least one sample with detectable lead levels before and after the LSL replacement and flushing (A11, A12, and B12), the peak lead did not occur at the same profile volume (see next item).
- The day before the LSL replacement and flushing, all samples at nine of the 12 locations were below the detection limit and the other three had peak lead in either the initial 0.5-L or final 0.5-L

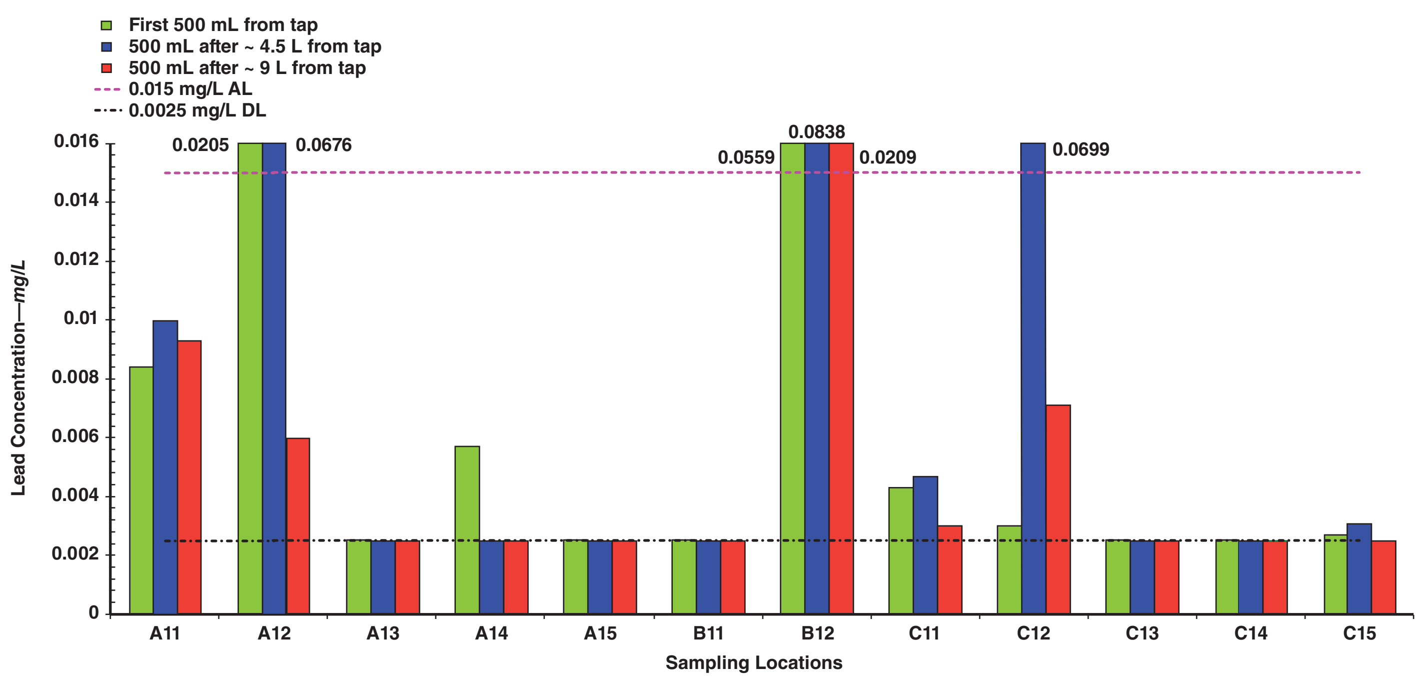
FIGURE 8 Utility N—samples collected before service line replacement



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

FIGURE 9 Utility N—samples collected on the first day after replacement and flushing



AL—action level, DL—detection limit

A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

TABLE 5 Information regarding study locations at utility N

Flush Conditions	10-Min Outdoor					20-Min Outdoor		10-Min Outdoor, 30-Min Indoor				
Customer location name	A11	A12	A13	A14	A15	B11	B12	C11	C12	C13	C14	C15
Material in customer side of service line	Lead	Lead	Copper	Copper	Galv-PE	Lead	Lead	Lead	PE	Lead	Lead	Lead
Length of service line replaced—*ft*	40	6	9	32	14	7	24	11	11	10	8	10

Galv-PE—short section of galvanized iron between lead service line on utility side and PE entering house, PE—polyethylene (plastic)

sample (~ 9 L—see Table 1). By contrast, one day after LSL replacement and flushing, seven locations had at least one sample above the detection limit, with the peak lead occurring in the middle (4.5-L) sample at six locations (A11, A12, B12, C11, C12, and C15) and one in the initial 0.5-L sample (A14).

- There is no conclusive trend in the relationship between the amount of lead pipe replaced and lead levels observed before and one day after replacement. Two of the longest service lines replaced (> 20 ft) were at A11 and B12, and these have higher lead content than most other locations reported in Figures 8 and 9. However, location A12 was shorter and had lead content above the action level, and A14 was longer and typically had lead content below the detection limit (this location has copper on the customer side, so after replacement, both the utility and customer sides of the service line are copper).

The results suggest that even with flushing, the results are higher one day after replacement than before. This is expected because of the amount of disturbance associated with the replacement activities. It is not known what the lead levels would have risen to after partial LSL replacement if no flushing took place or whether subsequent samples a month or more later had been collected. Consequently, as in the other two utilities studied, results after one month or more are needed to evaluate the potential benefit of flushing, or to determine whether there is any difference between flushing inside the house (C locations) versus outside the house (A and B locations).

Summary/discussion. Figure 10 is a summary of all the data for utilities X and P (utility N was not used because there were no samples collected after the first day). Sample results are labeled "A" (10-min outdoor flush), "B" (20-min outdoor flush), and "C" (10-min outdoor flush followed by a 30-min indoor flush) and plotted as nine groups. The first three groups are samples from one day after replacement, the next three from one month later, and the last three groups are two months after replacement. Note that each group also indicates whether the sample collected was the first (0.5 L), middle (4.5 L), or last (9 L) sample in the profile (see Table 1). Most results, including the outside-flushing approaches (A or B), were lower in later months than on the first day after replacement.

The increased flushing outside the house from 10 to 20 min did not produce noticeable improvements. This was true for all three sample volumes collected (see 500-mL samples in Table 1). By contrast, the data suggest that the indoor flush by the customer may provide additional lead reduction. This was reflected in the following trends for samples with flushing inside the house (C) versus only outside the house (A and B): (1) generally lower lead levels (in Figure 10, after one month the median of C locations was always lower than one or both medians from A or B locations); (2) lower percentage of results above the action level (2 versus 21%); and (3) greater percentage of results below the detection limit (83 versus 60%).

Using data from the first day after partial LSL replacement for all three water systems studied, the 0.015 mg/L action level was exceeded only at two of the 12 locations where the customer flushed the lines by opening all of the taps. Conversely, 12 of 19 locations exceeded the action level the day after replacement using only hose bib flushing (Types A and B). In subsequent first- and second-month samples, the lead levels improved in all cases. Consequently, about the same percentage (~ 3%) of customer flush locations (C) and outdoor utility-flushed locations (A and B) were above the 0.015 mg/L action level in the first- and second-month samples.

Locations flushed by the customer inside the house were more likely to be below the detection limit than in locations flushed outside the house by the utility, especially in samples collected more than one day after LSL replacement and flushing. In about 20% of the samples collected the day after flushing, the lead levels were below the detection limit in both the customer and the utility-flushed locations (0.001 and 0.003 mg/L detection limit for utilities X and P, respectively). By contrast, while the percentage of results below the detection limit was similar on the first day after LSL replacement and flushing, locations flushed by the customer inside the house were more likely to be below the detection limit (87%) than at locations where the service line was flushed only outdoors by the utility (62%).

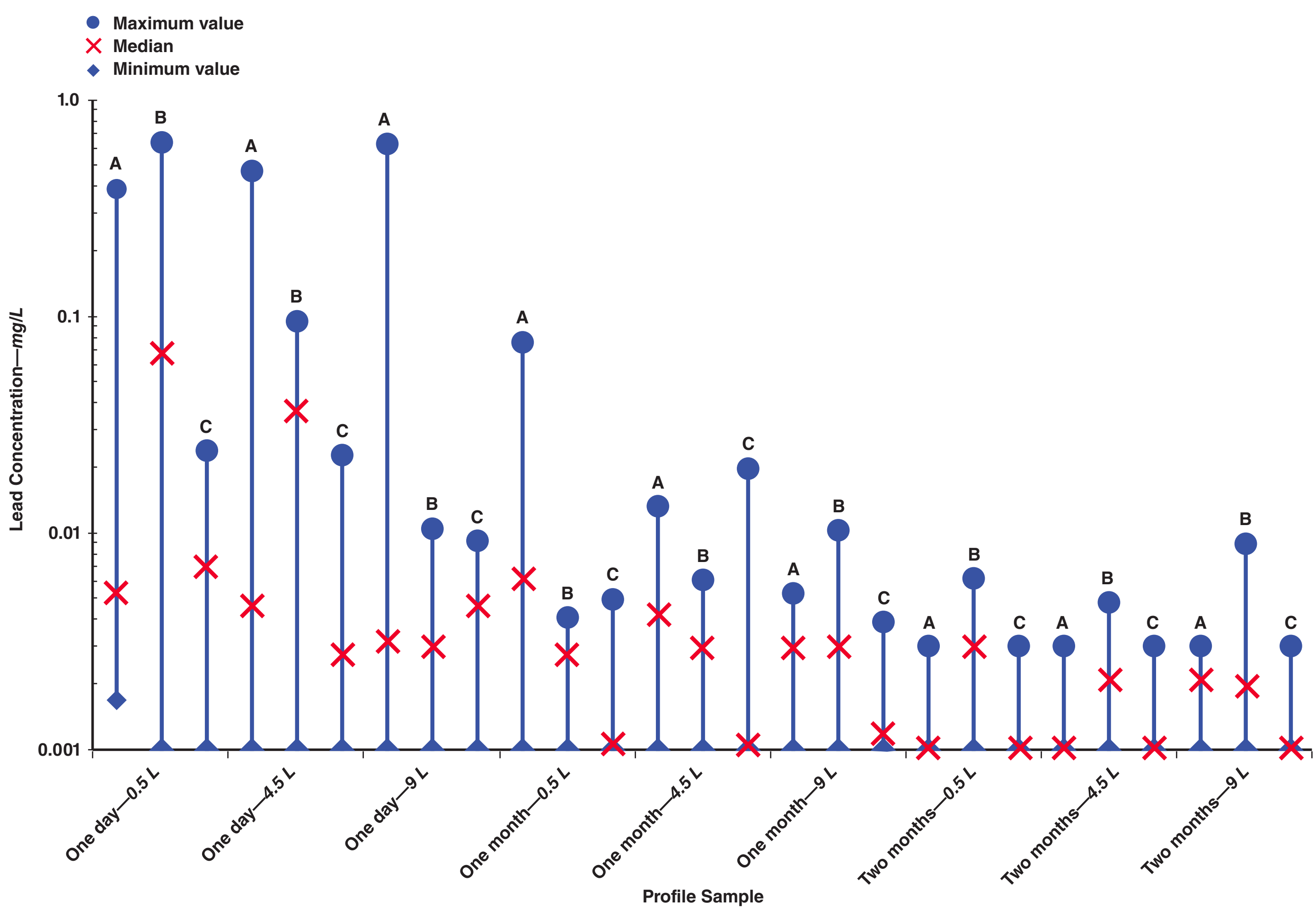
Although the number of observations is limited, they certainly suggest that a homeowner-flush program could be beneficial and could help reduce lead exposure after a partial LSL replacement.

CONCLUSIONS/RECOMMENDATIONS

The following conclusions, recommendations, and summary observations were made from the information presented in this article:

- Flushing inside the house by the customer opening all the indoor taps was potentially more effective than flushing conducted outside the house by utility staff opening a hose bib. The indoor flush targeted dislodgement and removal of lead associated with particulates both in the service line and the indoor plumbing, while the outdoor utility flush primarily affected the service line, with limited effect on the premise plumbing.

FIGURE 10 Comparison of all data from all dates at utilities X and P



A = 10-min outside flush, B = 20-min outside flush, C = 10-min outside flush plus 30-min indoor flush

• On each sample date, three samples were collected from the tap after the water had been stagnant for at least 6 h overnight (0 to 0.5 L [0 to 0.13 gal], 4.3 to 4.8 L [1.13 to 1.26 gal], and 8.6 to 9.1 L [2.26 to 2.40 gal]). There was no specific trend regarding which profile volume produced the peak lead value at all locations (i.e., at some locations it was the first 0.5-L sample, at others the 4.5-L sample, and at others the 9-L sample). Furthermore, there was no evidence that the peak lead occurred at the same profile volume at a given location on previous or subsequent sample-collection dates.

• Future studies appear warranted to further assess one-time, whole-house flushing events, like those studied in this research; other studies could look at flushing repeated at different frequencies. Future studies should also evaluate the magnitude of flushing velocities required to dislodge particulates in household plumbing versus practical limitations on household pipe velocities attainable just by opening household taps.

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PEER REVIEW

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