Effect of Partial Lead Service Line Replacement on Total Lead at the Tap

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Project summary

As the largest water supplier in Rhode Island, Providence Water Supply Board (ProvWater) provides drinking water to 60% of the state's residents. The system's water has been near or above the US EPA's lead action level of 15 parts per billion (ppb) since the inception of that agency's Lead and Copper Rule in 1991. In 2006, following a change in treatment that was intended to reduce lead solubility, the action level was exceeded; this triggered a requirement for ProvWater to begin a lead service line replacement program.

A lead service line replacement program is required by Section 6.84 of the *Rules and Regulations Pertaining to Public Drinking Water* [R46-13-DWQ]. Specifically, the water system is required to replace that part of lead service lines that the water system owns, which is the segment between the water main and the curb stop. Replacements must proceed at a rate of 7% per year until all are replaced, or until the water system no longer exceeds the Lead Action Level at more than 10% of the sites it samples. The system is also required to offer to replace the property owners' part, from the curb stop into the building, at the owners' expense. In today's housing market, few property owners (1-2%) are choosing to replace the so-called "private side", so most lead service line replacements are partial, or PLSLR.

A study published in 2008 by AwwaRF[1] found that lead service lines contribute up to 75% of the lead in drinking water. In a study published by the CDC in December 2010[2], children in homes with PLSLR and children in homes with intact lead service lines were both found to have an increased chance of elevated blood lead; there was no significant difference between children in homes with an intact lead service line and in homes with a partially replaced one. This lead to some speculation that partial lead service line replacements were not effective at reducing lead exposure through drinking water.

It is understood that a full service line replacement is the ideal, but the issues of ownership of the private side of the line and finding funding sources for the associated cost have not been overcome; meanwhile, the requirement to perform partial replacements is in regulation. The Rhode Island Department of Health (RI HEALTH) wanted to quantify the benefit, or lack thereof, of PLSLR, in terms of total lead delivered to the tap, and the time scale over which the change is seen.

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[1] AWWA Research Foundation (2008) Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues

[2] CDC (Centers for Disease Control and Prevention) 2010 Association between children's blood lead levels, lead service lines, and water disinfection, Washington, DC, 1998-2006

The RI HEALTH Study

The goal of the study was to quantify the change in both first-draw lead concentration, and the total mass of lead at the tap, following a partial service line replacement. To do this, RI HEALTH recruited eight residents whose homes were scheduled to have a PLSLR during the study period, and took a series of water samples before and after PLSLR.

All of the sites in the study were single-family homes built between 1930 and 1948, and all had mostly threaded brass pipe for their internal plumbing. Where remodeling had been done, segments of brass had been replaced by PVC or soldered copper pipe. None of the sites had whole-house water treatment. Sites were concentrated on three adjacent streets, with one site a half-mile away. Two sites were long-side service (the water main on the opposite side of the street), the other six were short-side (the house on the same side of the street as the water main).

A team from RI HEALTH visited each home before the PLSLR to measure the plumbing (length and diameter, and material) from the water main in the street to the kitchen tap. Notations were made concerning hot water feeds, ice makers, etc. The team scheduled a visit to take a series of samples intended to capture the full volume of water between the main and the tap after a six-hour stagnation. Samples were collected in one-liter Nalgene bottles that had been acid washed by the RI HEALTH lab. Samples were delivered to the lab within 24 hours, and preserved by the lab with acid. Analyses were performed using EPA Method 200.8 within the prescribed holding time.

Following the PLSLR, residents were asked to take a series of sample sets themselves. Each set was to be a one-liter first-draw sample (after six hours stagnation) and a one-liter sample after allowing the water to "run until cold". This was done three times: 12 hours after the PLSLR, three days after, and two weeks after. After each sampling event, we collected the bottles that day and left fresh bottles. Four months after PLSLR, we re-visited each site and repeated the full sequential sampling process (Table 2).

Pre-PLSLR sequential sampling showed similar patterns in all houses, and though the actual levels were quite variable, all had lead at some point above the action level of 15 parts per billion. An error in calculating the volume of water between main and tap resulted in taking four times the number of one-liter samples than were necessary in the first sequential sampling event. However, this mistake lead to an interesting finding: lead concentrations at all the sites failed to drop off after the entire calculated volumes had been drawn; in some cases, over four times the calculated volume had been collected and lead readings were still above the EPA Action Level of 15 parts per billion. We speculate that this is caused by turbulent flow within the service line and interior plumbing, resulting in mixing fresh water from the main with lead-containing water that had been stagnant in the service line.

The residents' sampling showed the expected spike immediately following PLSLR. The three-day samples showed a decline in all cases, and by two weeks, levels were at or below the pre-PLSLR readings. After four months, in all cases but one, both first-draw and run-until-cold samples showed a reduction in lead concentration. (The one case, Site #7, demonstrated the long flushing time necessary; the site had very low lead to begin with and showed a significant reduction in total lead overall.) Also, at Site #2, a spike in both lead and copper was observed at sample #16 (eight liters into the system) that is unexplained; a team will re-visit that site to take another full set of samples in the coming weeks.

The follow-up full sequential sampling, four months after PLSLR, showed a large decline in the total mass of lead delivered to the tap (Table 1), as well as a greatly reduced flushing time necessary to move all stagnant lead-containing water out of the internal plumbing. All sites showed both first-draw and flushed samples to be below the action level of 15 parts per billion. It should be noted that six sites out of eight still had at least some samples with concentrations above the action level, probably due to the remaining lead portion of the service line. The average reduction of total mass of lead at the tap (in comparable volumes of water) was 62%, with a low of 36% and a high of 79%. The average mass reduction was 210 micrograms, with a minimum reduction of 41 micrograms and a maximum reduction of 562 micrograms. The two sites with the highest mass of lead, and the longest flushing times, Sites #5 and #8 , showed the most dramatic reduction in both mass and flushing time.

Limitations, conclusions, and suggestions for further study

The first and most obvious limitation of this study is the small sample size. Of the two hundred homes scheduled to have PLSLR during the study period, we were able to recruit eight. The participants were self-selected, but did not appear to have sufficient knowledge concerning plumbing materials, water chemistry, etc. to have a particular bias. Participants appeared to follow instructions concerning sample collection, but this was difficult to verify with certainty; one sample was taken the same evening as the PLSLR and was clearly undrinkable due to the turbidity, as would be expected. Also, instructions for collecting the flushed sample were to "run until cold", which is imprecise, so introduces an unquantifiable error; there is no way to know if the water collected had been stagnant in the new copper pipe or in the remaining lead portion of the service line, though it was probably both.

High lead levels continuing past the calculated volume of the home's internal plumbing and service line is important when considering how to collect a good service line sample. In many cases, the peak lead concentration values occurred well beyond the calculated volume. One explanation is that water flow is turbulent, so service line water is mixing with fresh water from the main as it travels through the home's internal plumbing, thus diluting the highest concentrations and showing lead in a much greater volume of water. This would make it virtually impossible to get a discrete "service line sample" from a tap several feet downstream.

Eight homes may not be a large number, but the results were consistent enough to be compelling. All homes showed a reduction in total lead at the tap. The homes with the highest initial lead levels showed the greatest reduction in both lead and flushing time. The measured reduction of lead in water shows the PLSLR program to have a benefit in terms of reducing exposure, whether flushing advice is followed or not.

RI HEALTH would like to continue this project by returning the homes we have sampled after ProvWater stabilizes its water chemistry. It is expected that the increased carbonate alkalinity that ProvWater is introducing in the near future will reduce lead solubility from all sources, including what is left of the lead service lines at these locations, but we have no firm estimate of how long that process may take.

A larger study would serve to confirm or refine the results we found in Cranston. One suggestion that would not involve trying to coordinate with a partial service line replacement program would be to recruit participants from among homes that have already had partial replacements, and from among homes that have not had partial replacements. A large enough sample group in each category would have to be enlisted to overcome other factors that may affect the outcome, such as total length of line and age and material in internal plumbing. Such a study would result in better advice for how long a tap should be flushed to reduce lead exposure, with or without a partial service line replacement.

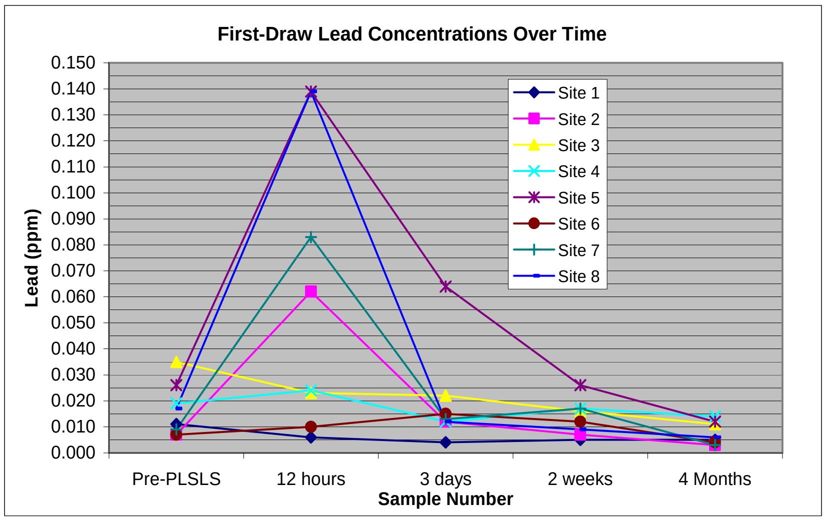
The public health message concerning lead in drinking water has focused largely on flushing, but this study showed a much longer flushing time was necessary to clear the lines of lead bearing water than had previously been assumed. The partial replacements done in the homes studied greatly decreased this flushing time; even after the partial replacement, the volume needed to flush the lines was greater than the calculated volume of the pipes, sometimes more than twice the calculated volume. As EPA considers modifying the language in its public education requirements, this should be considered, and further study done to determine both the cause and the extent of the phenomenon.

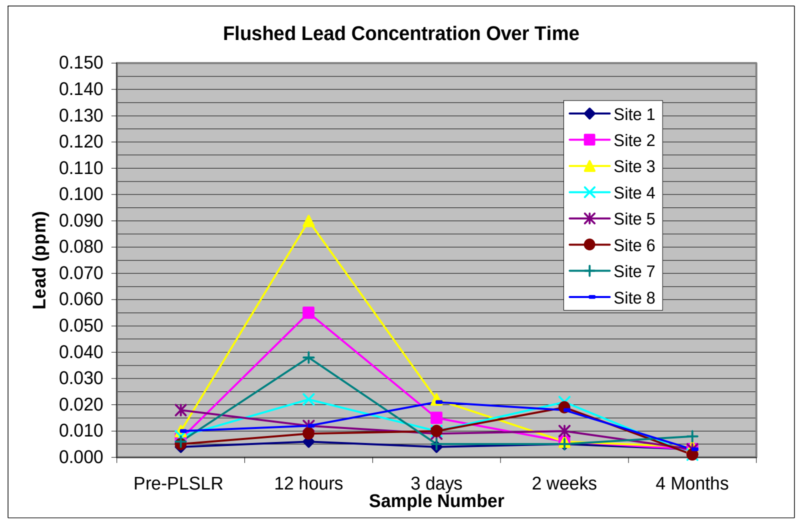
Table 1: Mass reduction in lead in comparable volumes of water after 6-hour stagnations

Site	Pb Mass Before PLSLR (mG)	Pb Mass After PLSLR (mG)	Mass Difference (mG)	Percent Reduction	Notes
Site 1	0.114	0.073	0.041	36%	Least reduction
Site 2	0.297	0.1855	0.112	38%	One anomalous result. Re-sampling scheduled for May.
Site 3	0.381	0.096	0.285	75%	Bottom of hill
Site 4	0.338	0.171	0.167	49%	
Site 5	0.712	0.151	0.561	79%	Bottom of hill; long-side service
Site 6	0.080	0.021	0.059	74%	
Site 7	0.073	0.0195	0.053	73%	Insufficient volume sampled - needs re-sampling
Site 8	0.586	0.187	0.399	68%	Bottom of hill; long-side service
		Average	0.210	62%	

Table 2: First-draw and "run until cold" samples taken after 6-hour stagnations, before and at intervals after PLSLRs (all results in parts per million)

site	PLSLR date	Pre-PLSLS	Pre-PLSLR	first sample date & time	12 hours	12 hours	second sample date & time	3 days	3 days	third sample date & time	2 weeks	2 weeks	4 Months	4 Months	4 Months		
		first draw	run until cold		first draw	run until cold		first draw	run until cold		first draw	run until cold	Date	First Draw	Run Until Cold	net change, first draw	net change, run until cold
1	8/25/2010	0.011	0.004	8/26/2010	0.006	0.006	8/31/2010	0.004	0.004	9/10/2010	0.005	0.005	2/14/2011	0.005	0.003	0.006	0.001
2	9/7/2010	0.007	0.007	9/9/2010	**0.062**	**0.055**	9/10/2010	0.012	0.015	9/21/2010	0.007	0.006		0.003	0.003	0.004	0.004
3	9/9/2010	**0.035**	0.010	9/11/2010	**0.023**	**0.090**	9/13/2010	**0.022**	**0.022**	9/25/2010	**0.016**	0.006		0.011	0.004	0.024	0.006
4	9/15/2010	**0.019**	0.008	9/16/2010	**0.024**	**0.022**	9/18/2010	0.012	0.010	10/1/2010	**0.017**	**0.021**		0.014	0.001	0.005	0.007
5	9/16/2010	**0.026**	**0.018**	9/18/2010	**0.139**	0.012	9/20/2010	**0.064**	0.009	10/1/2010	**0.026**	0.010		0.012	0.003	0.014	0.015
6	9/22/2010	0.007	0.005	9/23/2010	0.010	0.009	9/24/2010	0.015	0.010	10/6/2010	0.012	**0.019**		0.004	0.001	0.003	0.004
7	9/23/2010	0.009	0.006	9/24/2010	**0.083**	**0.038**	9/27/2010	0.013	0.005	10/7/2010	**0.017**	0.005		0.003	0.008	0.006	-0.002
8	9/29/2010	**0.017**	0.010	9/30/2010	**0.139**	0.012	10/3/2010	0.012	**0.021**	10/14/2010	0.009	**0.018**		0.006	0.003	0.011	0.007





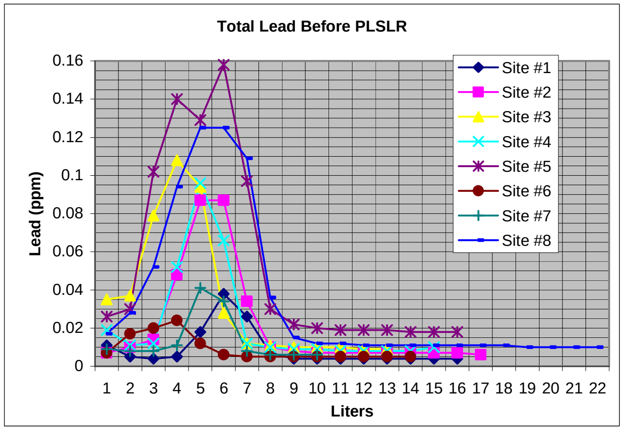
Pre-PLSLR and 4-month "Flushed" values were the lowest levels at which lead stabilized during sequential sampling. Other values were the results of samples taken by residents. Instructions were to "run water until cold", so some variability in location of water sample in pipe is to be expected and is unquantifiable.

Table 3: Sequential sampling results before, and 4 months after, PLSLR

Sequential Sampling Results, Auburn neighborhood, Summer 2010

all results in parts per million

Liter #	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Year Built:	**1937**	**1932**	**1940**	**1927**	**1940**	**1920**	**1920**	**1920**
1	0.011	0.007	**0.035**	**0.019**	**0.026**	0.007	0.009	**0.017**
2	0.005	0.01	**0.037**	0.011	**0.030**	**0.017**	0.008	**0.028**
3	0.004	0.014	**0.079**	0.012	**0.102**	**0.020**	0.008	**0.052**
4	0.005	**0.048**	**0.108**	**0.052**	**0.140**	**0.024**	0.011	**0.094**
5	**0.018**	**0.087**	**0.094**	**0.096**	**0.129**	0.012	**0.041**	**0.125**
6	**0.038**	**0.087**	**0.028**	**0.066**	**0.158**	0.006	**0.034**	**0.125**
7	**0.026**	**0.034**	0.012	0.012	**0.097**	0.005	0.008	**0.109**
8	0.007	0.01	0.011	0.010	**0.030**	0.005	0.006	**0.036**
9	0.004	0.008	0.010	0.009	**0.022**	0.005	0.006	0.015
10	0.004	0.007	0.010	0.009	**0.020**	0.005	0.006	0.012
11	0.004	0.007	0.010	0.008	**0.019**	0.005		0.012
12	0.004	0.007	0.009	0.008	**0.019**	0.005		0.011
13	0.004	0.007	0.009	0.008	**0.019**	0.005		0.011
14	0.004	0.007		0.008	**0.018**	0.005		0.011
15	0.004	0.007		0.010	**0.018**			0.011
16	0.004	0.007			**0.018**			0.011
17		0.006						0.011
18								0.011
19								0.01
20								0.01
21								0.01
22								0.01



Sequential Sampling Results, Auburn neighborhood, Winter 2011

(500 mL samples, except Site #4)

Liter #	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
0.5	0.007	0.002	0.008	0.014	0.012	0.004		0.004
1	0.002	0.003	0.013	0.014	0.013	0.004	0.003	0.007
1.5	0.002	0.004	0.010	**0.080**	0.008	0.006	0.002	**0.016**
2	0.003	0.005	0.008	**0.080**	0.008	0.004	0.002	**0.024**
2.5	0.003	0.007	**0.019**	**0.029**	**0.029**	0.004	0.002	**0.033**
3	0.002	**0.022**	**0.037**	**0.029**	**0.042**	0.007	0.002	**0.052**
3.5	0.002	**0.032**	**0.034**	**0.017**	**0.042**	0.006	0.003	**0.064**
4	0.003	**0.044**	**0.034**	**0.017**	**0.045**	0.003	0.007	**0.057**
4.5	0.012	**0.048**	**0.021**	0.011	**0.043**	0.002	0.010	**0.044**
5	**0.024**	**0.045**	0.002	0.011	**0.026**	0.001	0.008	**0.028**
5.5	**0.028**	**0.042**	0.002	0.005	0.013			**0.016**
6	**0.025**	**0.032**	0.004	0.005	0.007			0.01
6.5	**0.017**	**0.017**		0.002	0.004			0.007
7	0.009	0.008		0.002	0.003			0.005
7.5	0.004	0.004		0.003	0.003			0.004
8	0.003	**0.056**		0.003	0.003			0.003