

APPENDIX III.E. 1 - LEAD SEQUENTIAL SAMPLING STUDY

DRAFT FOR PUBLIC COMMENTS

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Appendix III.E.1

Lead Sequential Sampling Study

Background

The purpose of this study is to gain a better understanding of the comparative influence of existing lead service lines (LSLs) and copper with lead solder (Cu w/ Pb) in addition to galvanized (GAL) plumbing downstream of an existing or replaced lead service line on lead levels at customers' taps.

Sequential sampling of individual homes was used to capture water quality samples representing various plumbing material types within a single premise to understand the amount of lead released from those materials.

Sequential sampling entails taking multiple water quality samples from a customer's tap, one after another, to discern how water quality changes throughout the premise plumbing and service line. Three categories of homes were sought to take part in the study: 1) homes with lead service lines (LSL), 2) homes with copper with lead solder (Cu w/ Pb) and 3) homes with galvanized (GAL) plumbing downstream of an existing or replaced lead service line. To date, thirty-two Denver Water customers' homes have been potholed in search of homes that meet the criteria of the study. This report highlights the results of the three rounds of quarterly sampling that took place in Q4 of 2018 as well as Q1 and Q2 of 2019.

Study Design

- The sampling methods used for this study were informed by the work of Michael Schock et. al as outlined in the presentation, "Lead Tap Sampling Approached: What Do They Tell You".
- Lead concentration were measured via the EPA method 200.8 and are presented as dissolved lead in this report.
- The sequential sample volumes outlined below were collected after a minimum 6-hour stagnation time from the cold-water kitchen or bathroom faucet.
 - o 125mL, 125mL, 250mL, 250mL, 250mL, 500mL (as many 500mL samples as necessary to capture service line volume back to the main based on a calculated volume of the plumbing system).
 - o Five additional 1000mL samples were collected at the end of the sequence after the 1st round of sampling to ensure that final sample represented water originating from the main and not sitting in the service line during stagnation.
- A volume weighted lead concentration of the first 5 samples (1000mL cumulative) was calculated to determine the "Calculated 1st Draw" lead concentration. This concentration represents the expected concentration of an LCR compliant first draw sample.

First Round Sampling Results

- *Lead Service Line Homes*
 - o Seven of the identified homes were confirmed by potholing to have lead service lines.
 - All results for the first-round sampling of LSL homes are shown in Figure 1 below.
 - The average "Calculated 1st Draw" lead concentration was 6.1 ppb.

- The average of the highest measured lead concentration from all LSL homes was 13.9 ppb. The maximum lead concentration for any LSL home was 23.4 ppb.
- *Copper with Lead Solder Homes*
 - Seven of the identified homes were confirmed by potholing and internal plumbing inspection to have copper with lead solder.
 - All results for the first-round sampling of Cu w/ Pb homes are shown in Figure 2 below.
 - The “Calculated 1st Draw” lead concentration for all Cu w/ Pb homes except one was below the minimum reporting limit (MRL) of 1 ppb.
 - The one exception (Garrison St.) had a “Calculated 1st Draw” lead concentration of 4.9 ppb and a maximum lead concentration of 8.6 ppb. It was hypothesized that the results from this home were artificially high due to particulate that was observed in the samples and believed to be caused by closing the hot water shut off valve for the “first time in 20 years”, according to the customer.
 - Re-sampling was performed at this home the following month and lead concentrations of all samples were below 1.7 ppb with a “Calculated 1st Draw” lead concentration of 1.2ppb. The re-sampling results are labeled “46XX S Garrison RS” in the Figure 2 below.
 - None of the Cu w/ Pb homes had a single sample with a lead concentration of 1.8 ppb or greater (initial Garrison results excluded).
 - The average of the highest measured lead concentration from all copper with lead solder homes was 1.1 ppb (2.2 ppb when including the initial Garrison results).
 - *Galvanized Plumbing Downstream of a Replaced Lead Service Line*
 - During the first round of sampling, no homes were identified to have galvanized plumbing downstream of an existing or previously replaced lead service line.

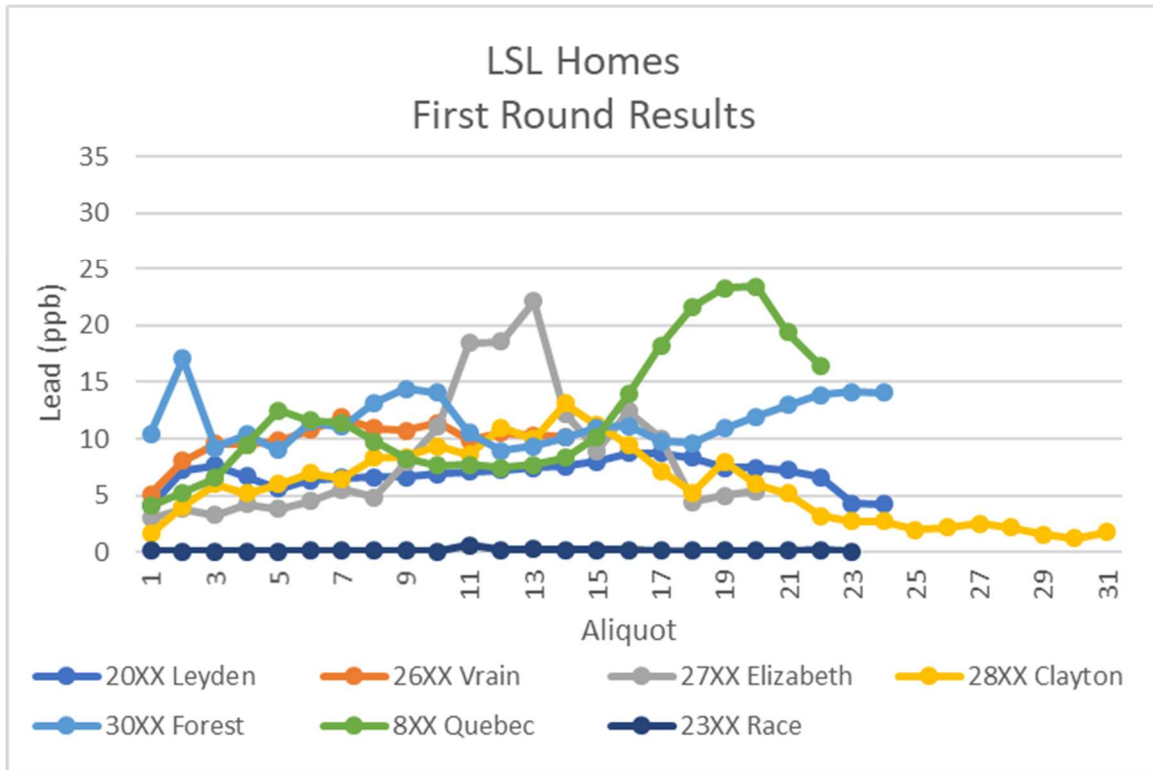


Figure 1 – First Round LSL Homes Results

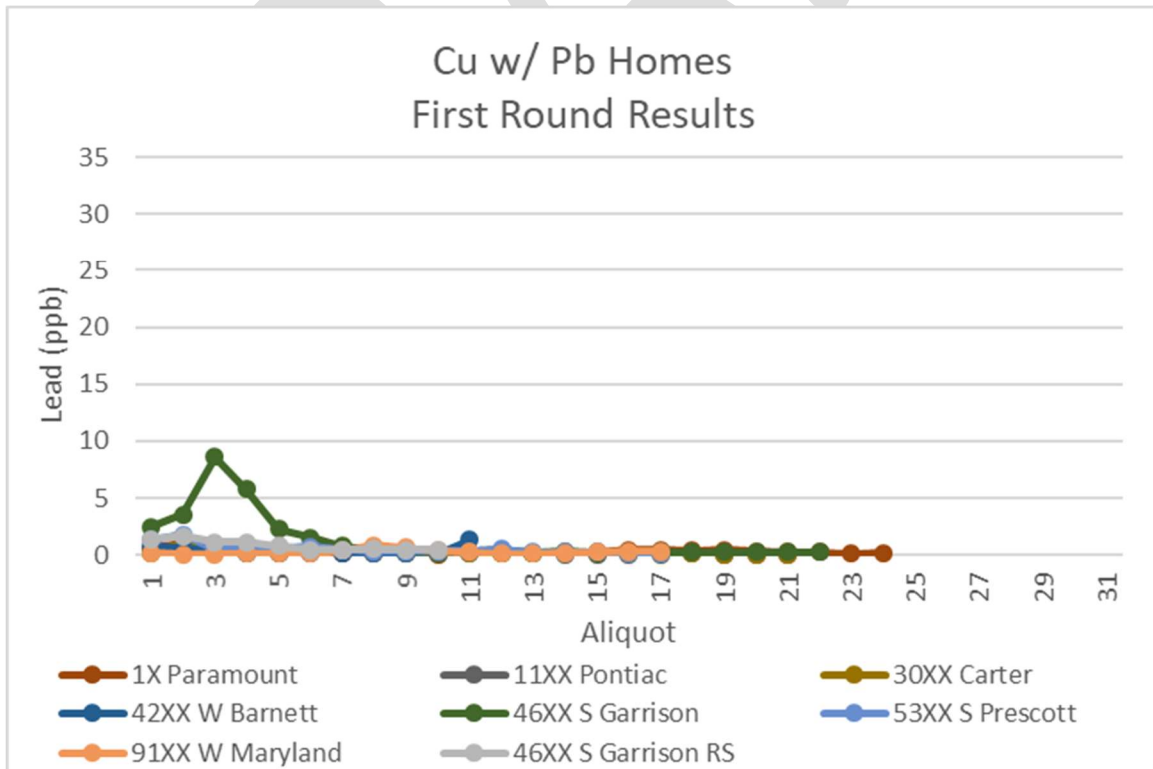


Figure 2 – First Round Cu w/ Pb Homes Results

Second Round Sampling Results

- *Lead Service Line Homes*
 - The same seven lead service line homes from the first round of sampling were sampled again 2-3 months later. Two additional lead service line homes were identified to represent portions of the distribution system not captured in the initial round of sampling for a total of 9 homes sampled.
 - All results for the second-round sampling of LSL and GAL homes are shown in Figure 3 below.
 - The 23XX Race St. home was confirmed to have a lead service line despite all samples measuring below the MRL.
 - The average “Calculated 1st Draw” lead concentration for LSL homes was 4.6 ppb.
 - The average of the highest measured lead concentration from all LSL homes was 15.9 ppb. The maximum lead concentration for any LSL home was 33.6 ppb.
- *Copper with Lead Solder Homes*
 - Six of the copper with lead solder homes sampled in the first round of sampling were sampled again 2-3 months later. One of the homes dropped out of the study.
 - All results for the second-round sampling of Cu w/ Pb homes are shown in Figure 4 below.
 - The average “Calculated 1st Draw” lead concentration for Cu w/ Pb homes was below the MRL.
 - The average of the highest measured lead concentration from all copper with lead solder homes was 1.5 ppb.
 - No sample from any of the Cu w/ Pb homes in the second round of sampling had a lead concentration greater than 4.3 ppb.
- *Galvanized Plumbing Downstream of a Replaced Lead Service Line*
 - All results for the second-round sampling of GAL home are shown in Figure 3 below.
 - Only one home with galvanized plumbing downstream of a replaced lead service line was identified for the second round of sampling. This home is identified as 11XX Mariposa in Figure 3.
 - Of all the 15 homes sampled, the galvanized home had the 3rd highest “Calculated 1st Draw” lead concentration at 8.6 ppb. The galvanized home also had the 3rd highest maximum lead concentration at 25.8 ppb.
 - The lead levels released from the galvanized home were similar to the lead service line homes.
 - It is of interest to note that lead levels spike earlier in the sampling sequence for the GAL line compared to LSLs. This is indicative of galvanized internal plumbing acting as a source of lead.

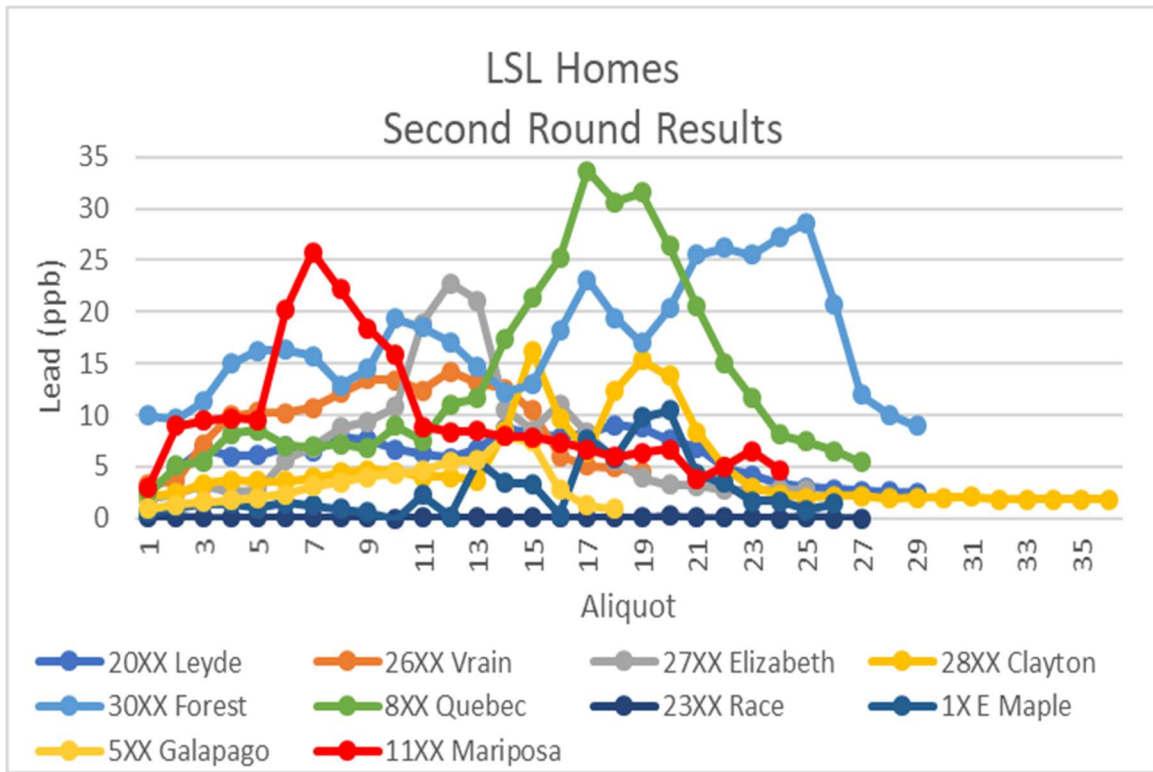


Figure 3 – Second Round LSL and GAL Homes Results

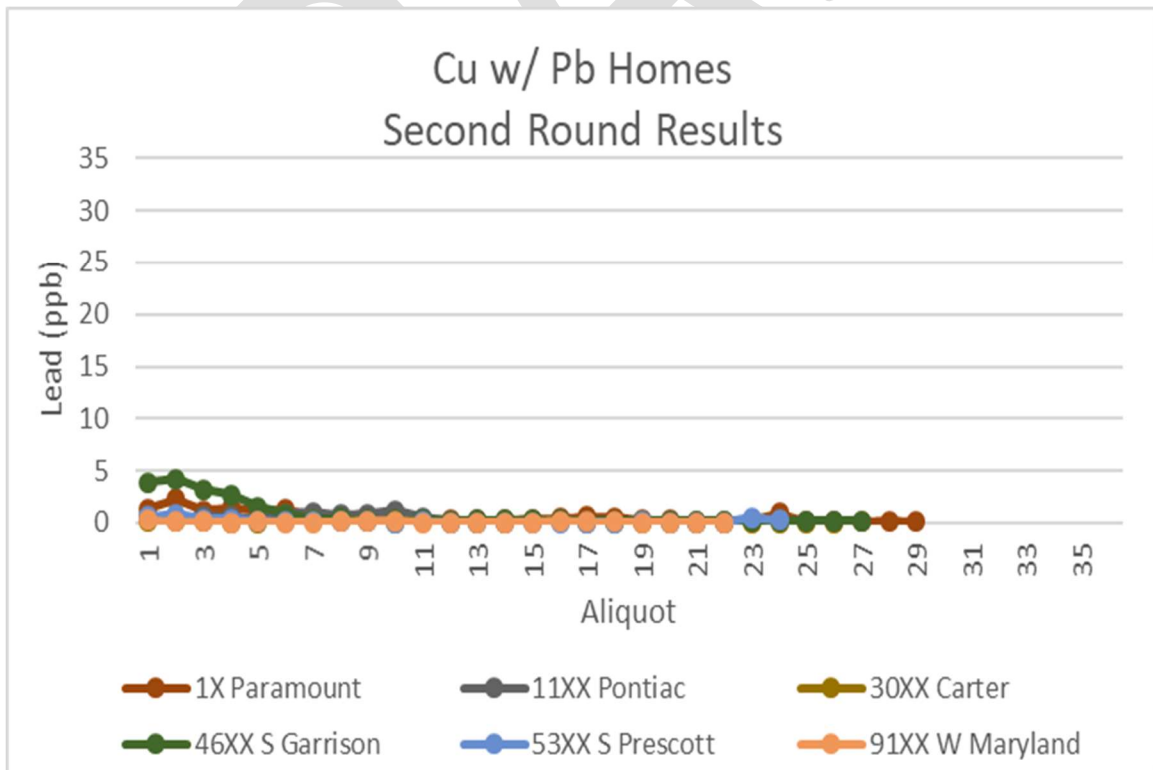


Figure 4 – Second Round Cu w/ Pb Homes Results

Third Round Sampling Results

- *Lead Service Line Homes*
 - For the third round of sequential sampling, one of the original homes (30XX Forest St) dropped out of the program. Eight LSL homes remained in the study for the 3rd round.
 - All results for the second-round sampling of LSL and GAL homes are shown in Figure 5 below.
 - Overall, lead levels in all samples were significantly lower for the 3rd round of sampling. The highest measured lead value from any LSL home sample was only 10.4 ppb.
 - The average “Calculated 1st Draw” lead concentration for LSL homes was 1.8 ppb.
 - The average of the highest measured lead concentration from all LSL homes was 7.2 ppb.

- *Copper with Lead Solder Homes*
 - The six homes from the second round of sampling were sampled again for round three. However, the results for 46XX S Garrison were not available at the time of writing this report.
 - All results for the second-round sampling of Cu w/ Pb homes are shown in Figure 6 below.
 - Lead levels from Cu w/ Pb homes were significantly lower for the 3rd round of sampling. No sample from any of the Cu w/ Pb homes in the third round had a lead concentration above the MRL.
 - The average “Calculated 1st Draw” lead concentration for Cu w/ Pb homes was below the MRL.

- *Galvanized Plumbing Downstream of a Replaced Lead Service Line*
 - Despite multiple attempts to contact the owner of the GAL home, samples were not collected for the third round.
 - One other home has been identified that potentially meets the requirements of the study. At the time of writing this report, sample collection is being scheduled with the homeowner.

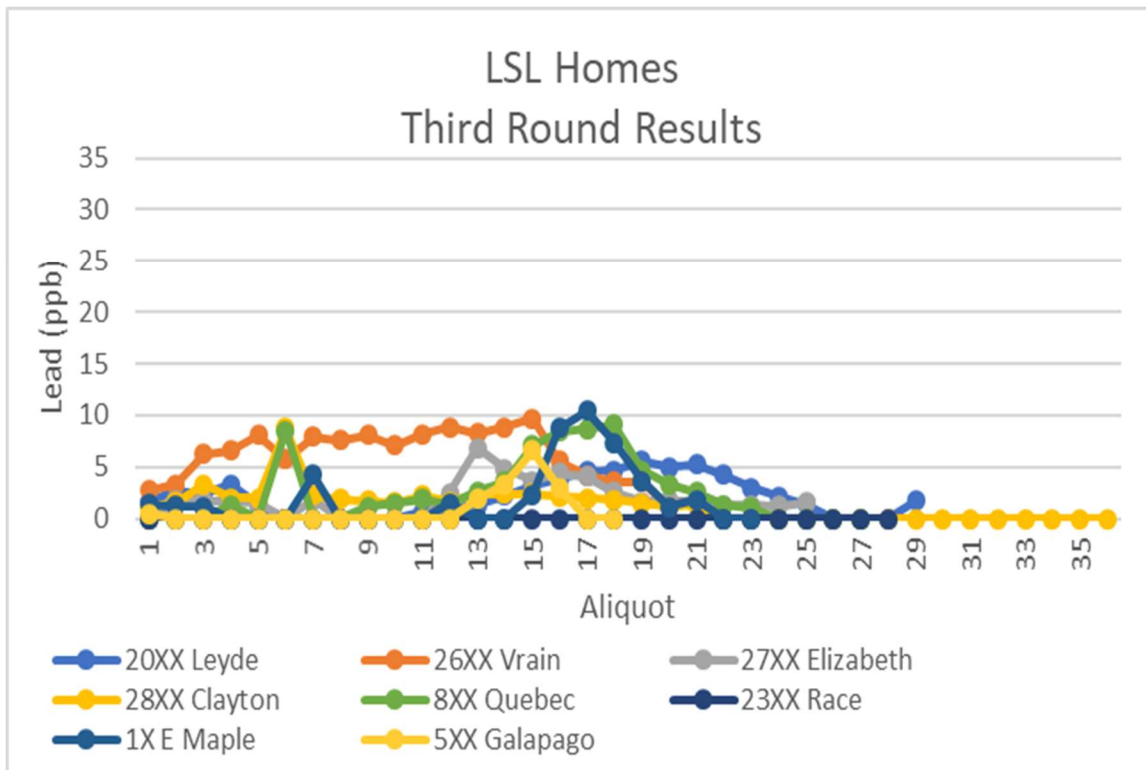


Figure 5 – Third Round LSL Homes Results

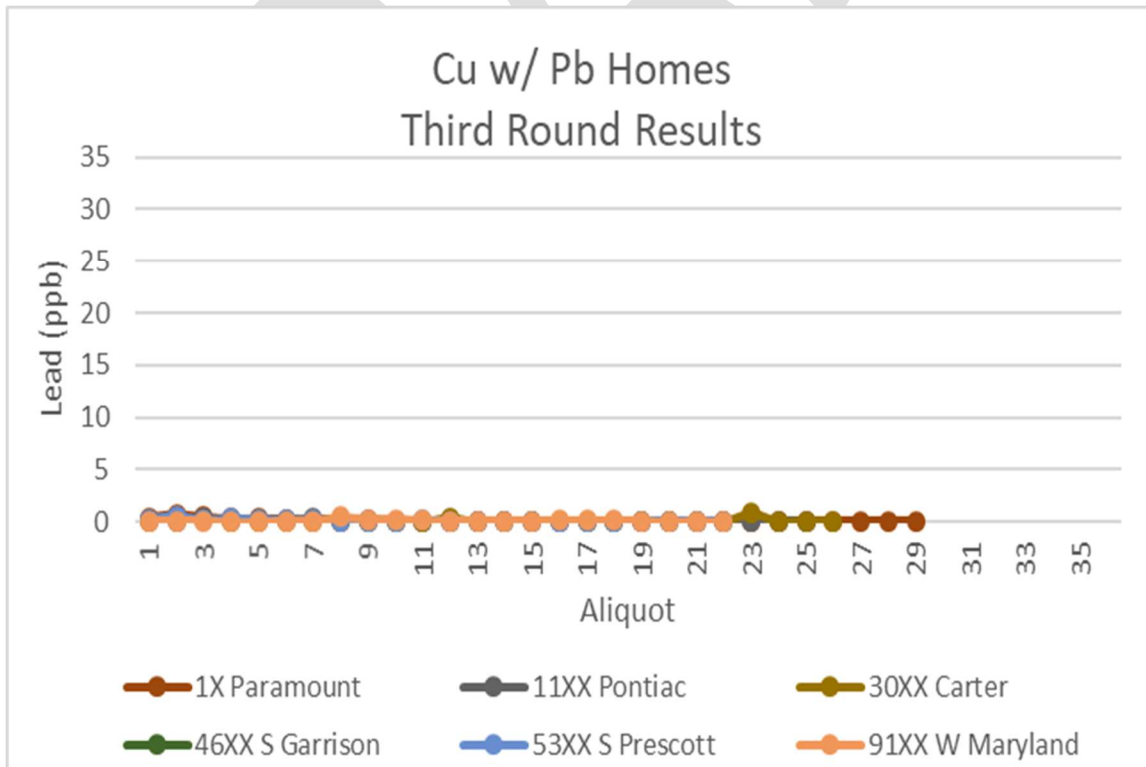


Figure 6 – Third Round Cu w/ Pb Homes Results

Conclusions

- Of the homes sampled in sequential sampling study, lead service lines overwhelmingly represented the greatest source of lead when compared to copper with lead solder.
 - o Not including the first-round initial sampling at 46XX S Garrison as explained above, all samples events at copper with lead solder (Cu w/ Pb) homes yielded maximum lead concentrations below 5 ppb.
 - o Conversely, all sampling events at lead service line (LSL) homes yielded maximum lead concentration greater than 5 ppb. The maximum Pb concentration measured from any LSL home was 33.6 ppb.
- The first liter of water from the tap, represented by the first 5 sample aliquots in this study and used to derive the “Calculated 1st Draw” lead concentration, contained nearly all the lead released from a copper with lead solder home in this study.
 - o Only 3 samples from Cu w/ Pb homes had a lead concentration greater than the MRL after the 5th aliquot (representing a 1-liter first draw). These three samples were all less than 1.4 ppb.
- The “Calculated 1st Draw” concentrations for lead service lines are lower than subsequent aliquots and therefore under-represents the amount of lead released from a lead service line home.
 - o Only one LSL home during one sampling round had a maximum lead concentration occur in the first five aliquots.
- The single galvanized home participating in the study yielded lead levels similar to LSL homes. However, the peak lead level in the GAL home occurred in an earlier sample in the sampling sequence compared to LSL homes.
 - o Caution must be used when viewing the results from the GAL home. The results from the single GAL home sampled in this study may not be representative of other galvanized homes within the distribution system.
 - o The lead results from GAL home are consistent with the hypothesis that galvanized pipe acts as a lead sink while downstream of a lead source (i.e. lead service line) and then acts as a lead source once the original source of lead has been removed.

Figures 6-10 summarize the lead results from the three rounds of sequential sampling. Lead concentrations below the reporting limit of 1 ppb are reported as 0 ppb.

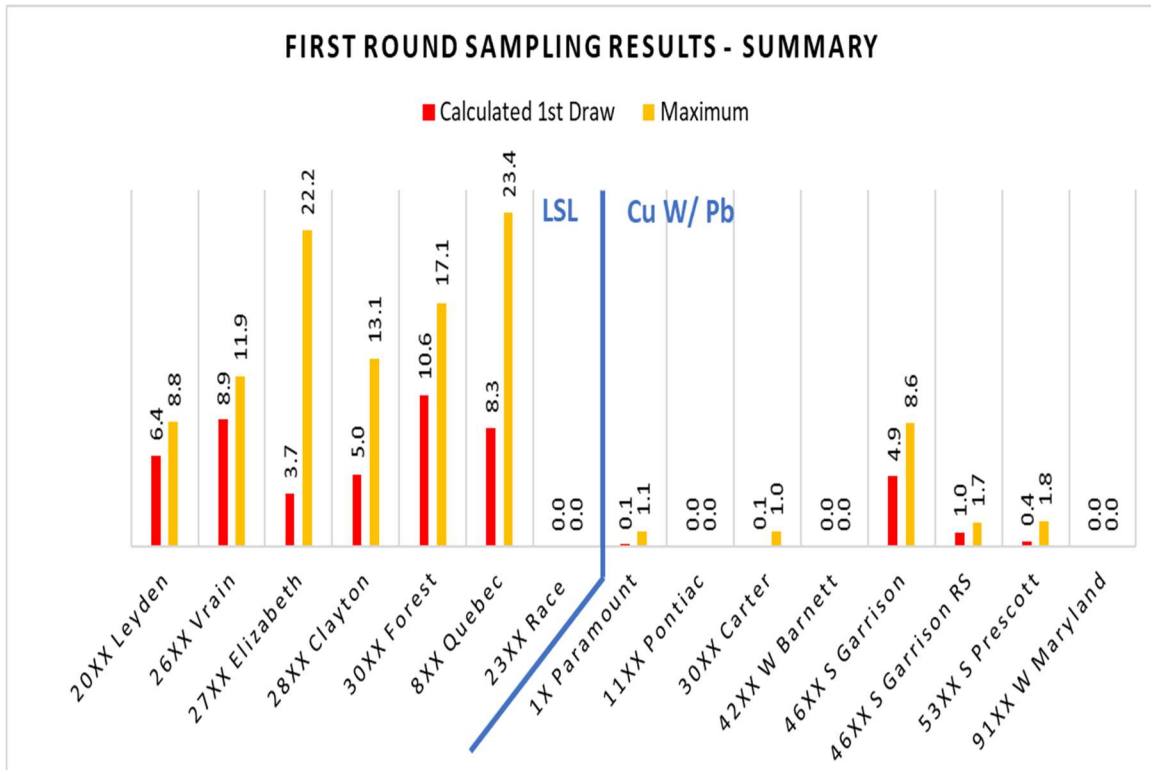


Figure 6 – First Round Sampling Lead Results as ppb

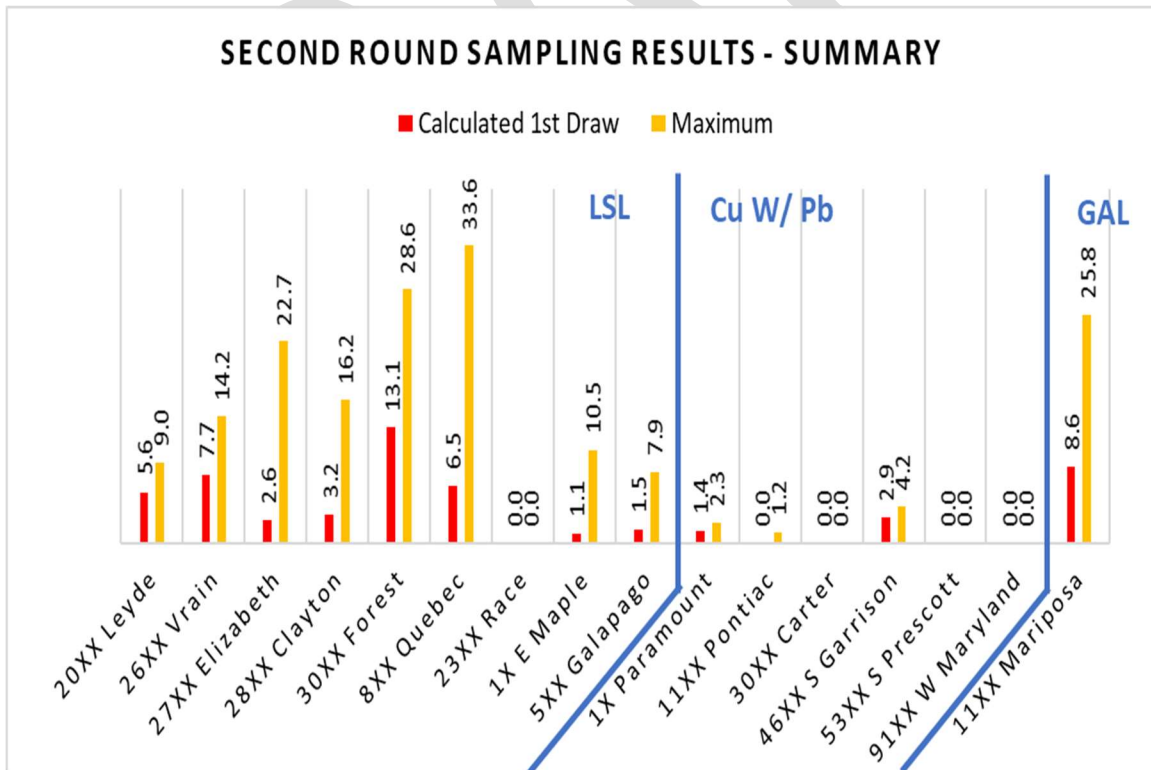


Figure 7 – Second Round Sampling Lead Results as ppb

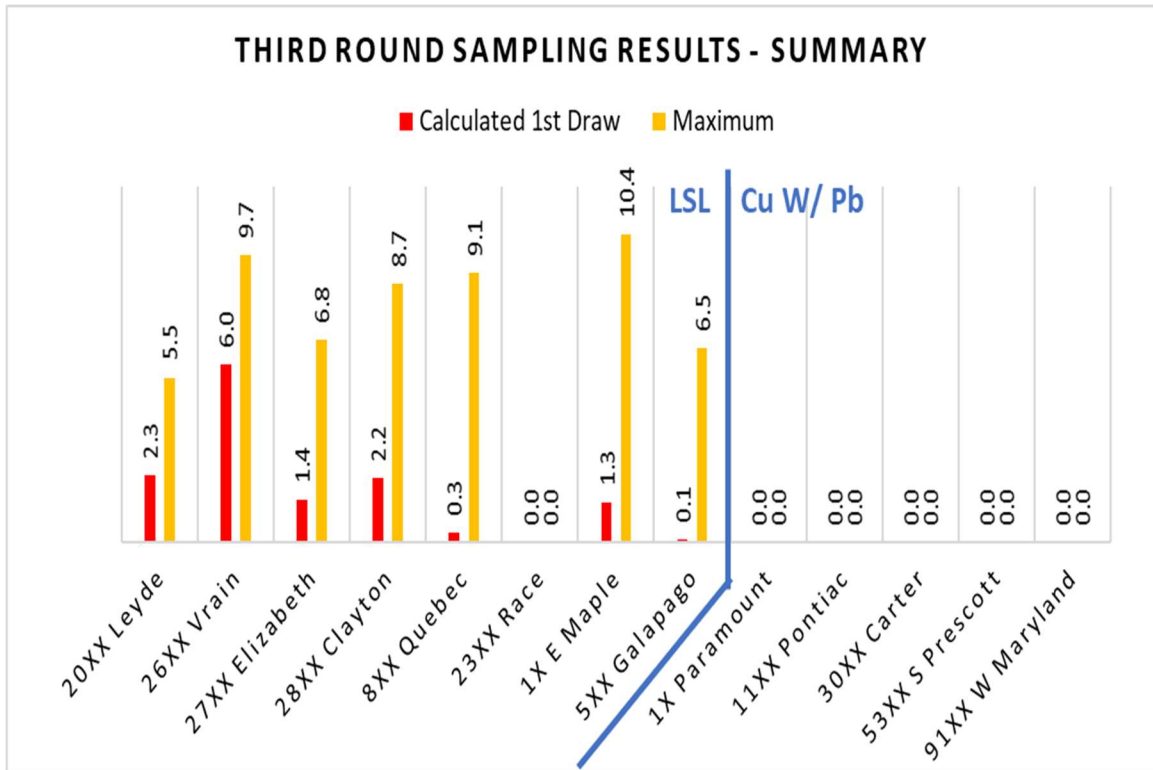


Figure 8 – Third Round Sampling Lead Results as ppb

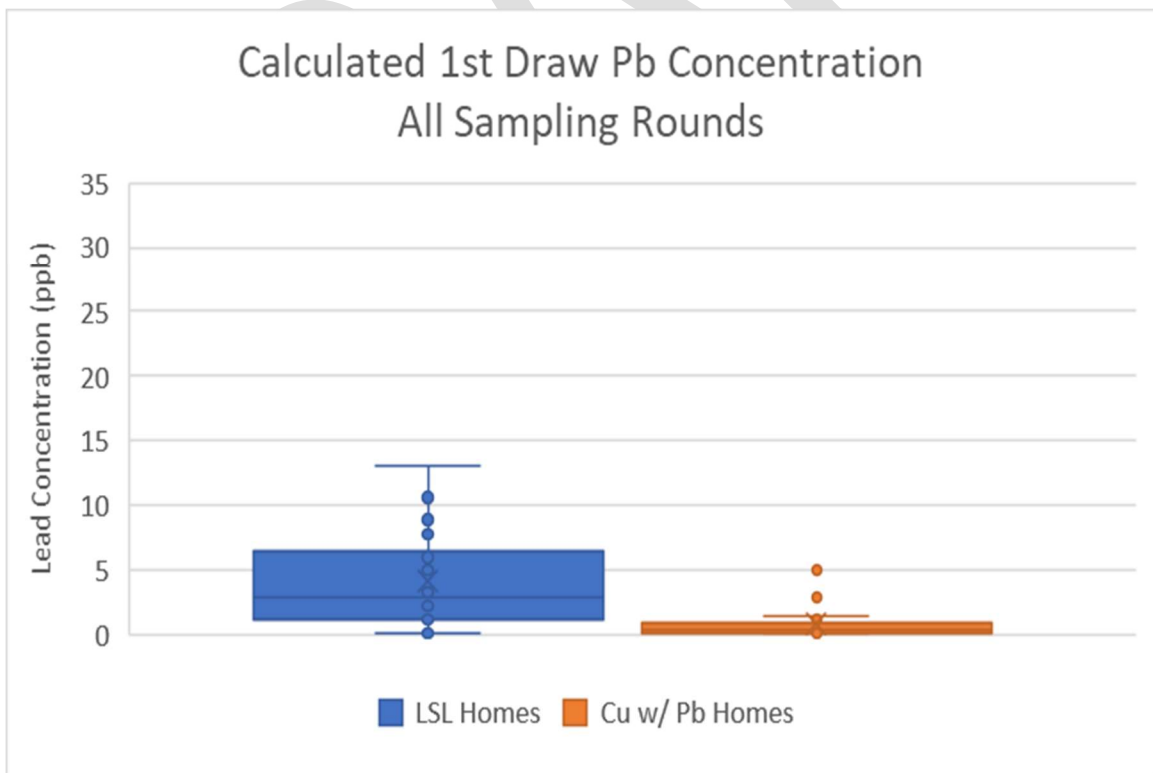


Figure 9 – All Results for Calculated 1st Draw Lead Concentration from Each Home Sampled

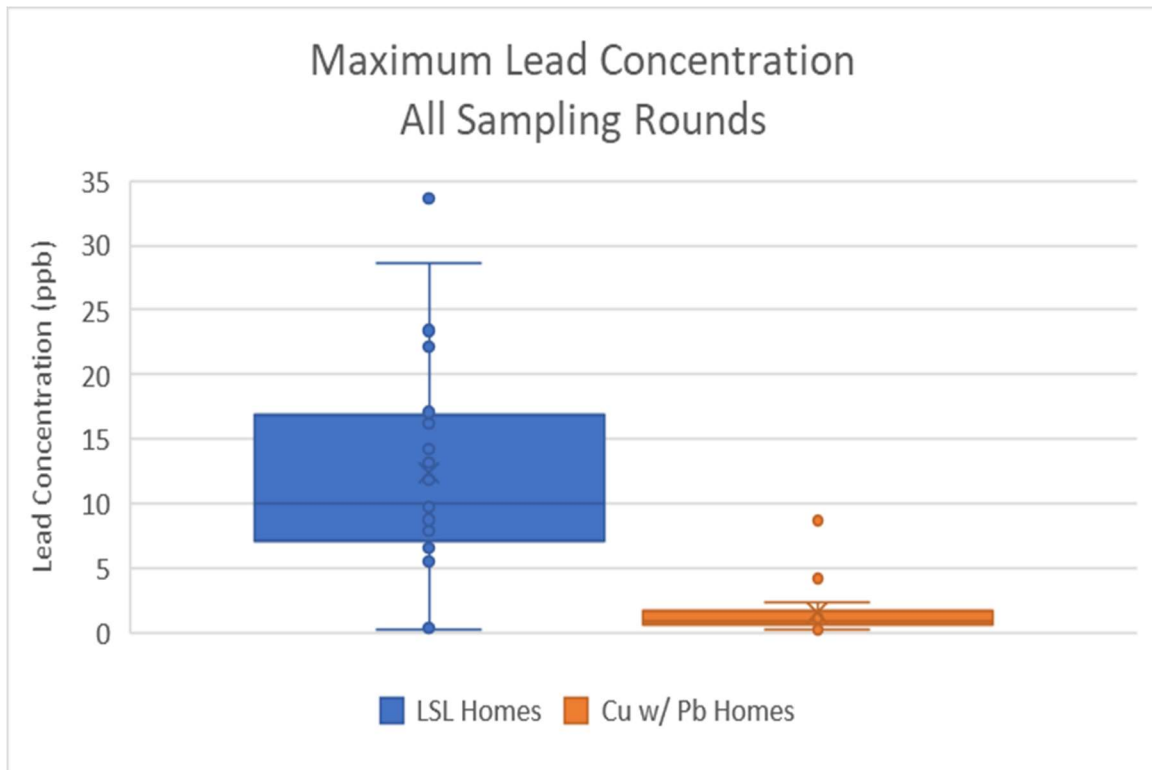


Figure 10 – All Results for Maximum Lead Concentration from Each Home Sampled

Sampling Method Comparison

Denver Water’s Customer Requested Lead Sampling program asks customers to collect three 1-liter samples following at least 6 hours of stagnation. The first 1-liter sample is collected immediately following stagnation before any water has passed through the premise. After the first sample is collected, customers are asked to flush for 25 seconds without shutting off the faucet. A second 1-liter sample is then collected. After the second sample is collected, the customer is asked to flush for an additional 25 seconds before collecting the third and final 1-liter sample. Denver Water has measured sampling flow rates when collecting lead samples and has found that flows typically range between 2-4 liters per minute. It is assumed that the flushing rate during the 3-Draw sampling is within this range.

The first 1-liter sample represents the same volume of water that is collected during LCR compliance sampling. This sample is thought to be most influenced by the sampling fixture and internal plumbing nearest to the fixture. The second sample is collected with the intent to capture the lead from internal plumbing without significant influence from the sampling fixture or the service line. The third sample is intended to represent the water stagnating in the service line.

Figure 11 and 12 show the lead concentrations from three homes sampled during the 2nd round of sequential sampling. The three homes include a lead service line home (8XX Quebec), a

copper with lead solder home (1X Paramount) and a home with galvanized plumbing downstream of a replaced lead service line (11XX Mariposa). Overlaid on these figures are the theoretical sample and flushing volumes corresponding to the 3-Draw sampling protocol described above. Note that the horizontal axis represents the aliquot or sample bottle with volumes detailed in the Study Design section above.

The homes selected are not intended to represent all homes of certain plumbing type. They were merely selected as an example. It is impossible to select a “representative home” because of the innumerable variables associated with lead sampling. For example, when looking at the aliquot in which the maximum lead concentration occurred in LSL homes, it varies from aliquot 13-27. This means that for lead service line homes, the maximum lead concentration could occur between the fifth and twelfth liter when sampling.

Given the number of variables that impact lead concentration captured during a sampling event (faucet flow, internal plumbing and service line length, stagnation time, flushing prior to stagnation, etc) and the resources required to process and analyze samples, Denver Water has concluded that the existing 3-draw sampling protocol is the most appropriate method to obtain consistent and reliable data on lead concentrations from homes when sampling lead is requested by customers.

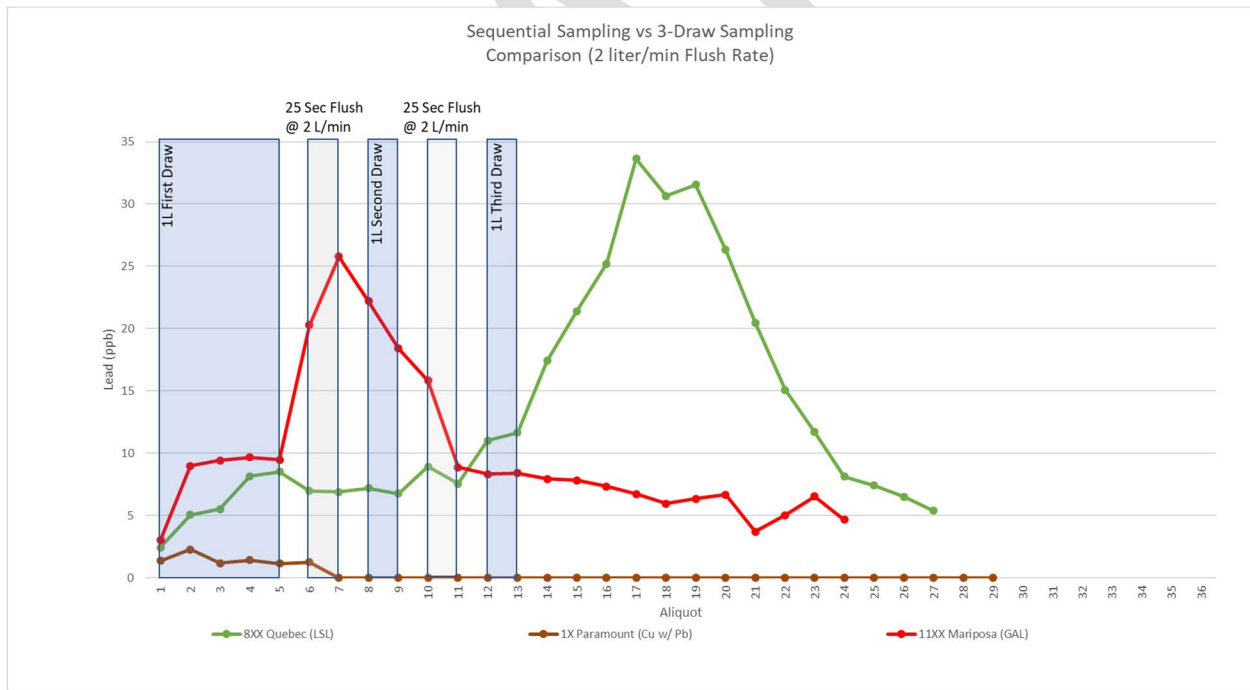


Figure 11 – 3-Draw Sample Volumes at 2 L/min Flushing Compared to Sequential Sampling Results

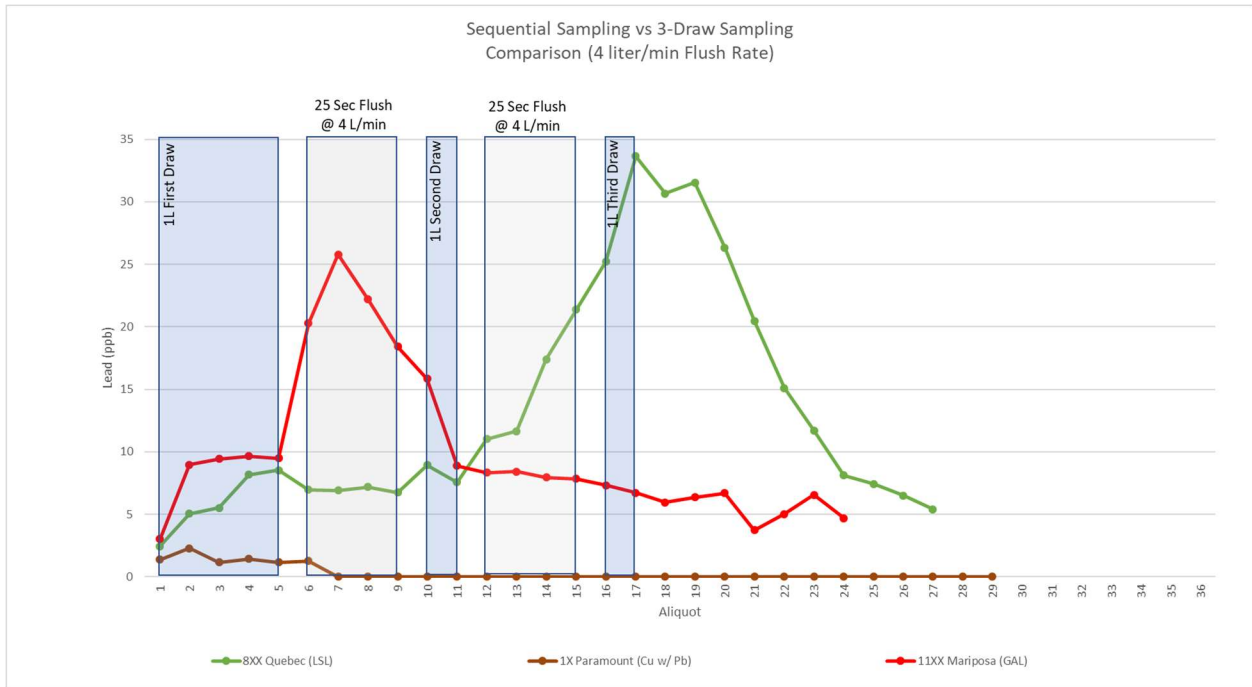


Figure 12 – 3-Draw Sample Volumes at 4 L/min Flushing Compared to Sequential Sampling Results