DATA REPORT: SUMMARY OF LEAD WATER RESULTS IN FILTER AND SEQUENTIAL STUDIES

EXECUTIVE SUMMARY

The EPA Office of Water (OW) requested the EPA Office of Research and Development (ORD) conduct a filter effectiveness study in Benton Harbor, Michigan in response to a Safe Drinking Water Act petition filed on behalf of the residents of Benton Harbor. ORD designed a study to evaluate filter effectiveness, identify lead (Pb) sources, and characterize particles within residences in Benton Harbor. This study was carried out in collaboration between EPA Region 5 and ORD from November 9 – December 17, 2021. Approximately 2,000 field samples were collected and analyzed, sampling 215 homes for the filter effectiveness study (resulting in 199 properly installed and operated filter study homes) and 26 homes for the sequential sampling study to evaluate premise plumbing and service line lead release. This data report provides an initial overview of the findings from the studies; a comprehensive final report will be provided in summer 2022. The results here show that all properly operating filter water samples were found to be below the NSF/ANSI 53 and bottled water certification (21 C.F.R. § 165.110) requirements of 5 ppb lead (FDA).

BACKGROUND

The City of Benton Harbor, MI, initially exceeded EPA's Lead and Copper Rule (LCR) lead action level (AL) in 2018, after which the State required the City to conduct monitoring every 6 months according to Michigan's new Lead and Copper Provisions of the Michigan Safe Drinking Water Act (1976 PA 399). The system continued to exceed the lead AL during five additional monitoring periods from January 2019 to June 2021; in the most recent monitoring round ending in December 2021 (EGLE, 2019, 2021a), the 90th percentile was equal to the lead AL. In response to the AL exceedances, the Michigan Department of Health and Human Services (MDHHS) through the Berrien County Health Department (BCHD) began providing the community with faucet-mounted point-of-use (POU) and pitcher filters certified by NSF/ANSI 53 for lead reduction to reduce the level of lead in tap water (News, 2019). In March 2019, the City began adding an 70% orthophosphate and 30% polyphosphate blended corrosion-control inhibitor at a target dose of 1.5 mg PO_4/L (EGLE, 2019, 2020). Based on the State of Michigan Department of Environment, Great Lakes and Energy (EGLE) evaluation of subsequent monitoring results, in its February 2020 designation of optimal corrosion control treatment (OCCT) (EGLE, 2020), EGLE directed the City to change to a minimum of 90% orthophosphate and 10% polyphosphate blend to achieve a 3 mg PO_4/L orthophosphate residual in the distribution system, with the system making the switch in March 2020 (EGLE, 2021c).

Concerns were raised over filter effectiveness as well as public education on proper filter use (uncertainty on how to properly install and maintain the filters) (Petitioners, 2021). A petition outlining the history of Benton Harbor's lead contamination issues and proposed actions was submitted to the EPA on September 9, 2021, and included a specific request that a filter lead removal study be conducted in Benton Harbor by EPA's Office of Research and Development (ORD). On September 30, 2021, a joint press release was issued by BCHD, MDHHS, and EGLE stating that bottled water would be made available to the residents of Benton Harbor (EGLE, 2021b).

At OW's request, ORD designed, and with the assistance of R5 and MDHHS, implemented a statistically sound filter effectiveness study. Sampling began on November 9, 2021, and concluded on December 17, 2021, after water from properly installed and operated filters had been collected in 199 Benton Harbor homes. In addition to the filter effectiveness study, ORD designed two additional studies: (1) to assess lead source contributions in premise plumbing, and (2) to characterize lead particles. A sequential profile sampling study was designed and performed that included 26 Benton Harbor homes to understand drinking water lead sources. A complementary lead particle and characterization study was performed that consisted of particle size fractionation and particle composition characterization. These studies are important considerations for corrosion control effectiveness and for characteristics of lead-containing particles that could jeopardize filter effectiveness.

The objective of this data report is to provide an initial overview of the findings from the (1) filter effectiveness, (2) sequential profile, and (3) particle size fractionation studies. This initial report is focused on the lead in water results given the prioritization of lead analyses, completeness of the lead dataset, and importance of the results. Chlorine data is also included here. Other water quality data, field observations, and additional study findings are still under analysis and review and will be reported in a follow-on report in summer 2022.

METHODS IN BRIEF

Table 1: Study team and roles

Responsibility	Personnel
Project Lead	Darren Lytle
Study Design	Darren Lytle, Mike Schock, Jennifer Tully, Val Bosscher
Field Sampling Team	EPA: Peg Donnelly, Jonathan Burian, Joan Rogers, Mari Nord, Daniel Williams, Christy Muhlen, Steve Harmon, Andrew Maguire, Claire Scheib-Feeley, Michelle Kerr, Cheryl Burdett, Mostafa Noureldin, Kevin Gaughan, Jodie Opie, Alexandria Flevarakis, Rob Thompson, Colin Geisenhoffer, Casey Formal (EPA contractor)

	MDHHS support to EPA sampling teams: Kevin Kasischke, Frank Schenkhuizen; Mannik Smith Group (MDHHS contractor) Mike DeLong, Jessica Bankey, Kevin Larr, Rabia Azam
Water Analysis Team	Heather Shoven, Amanda Wroble, Rob Snyder, Colin Breslin, Christina Rice, Colin Kramer, Ellie Hagen, Luis Antonio Flores, Kathleen Swan, Francis Awanya, and Edgar Santiago
Data Team	EPA: Val Bosscher, Jennifer Tully, Janice Huang, Jonathan Burian, Matthew Blaser, Lucy Stanfield, Eric Holbus, Jason Sewell, Samuel Blazey; EPA contractors: Scott Shilling, Matthew Pinelli, Megan Urbanic, Adam Peterca, Randy Dorian
Quality Assurance Review	Maily Pham, Jackie Adams
Report Preparation	Darren Lytle, Jennifer Tully, Mike Schock, Val Bosscher

Sampling site selection. Single-family residences served by the Benton Harbor Water Plant that were provided with PUR or Brita POU faucet filters or ZeroWater™ pitcher filters from BCHD were targeted for this sampling effort. The distribution of filter types sampled in homes (Figure 1) reflected the distribution of filter types provided to residents by the BCHD (89% faucet filters, 11% pitcher filters). Residences sampled for the filter effectiveness study were confirmed to not have whole-house filters, water softeners, or reverse osmosis units under the kitchen sink. Furthermore, schedulers targeted single-family residences with known lead service lines (LSLs), or with Benton Harbor documentation of being likely (assumed) to have an LSL. EPA completed best efforts to schedule sampling at the approximately 200 homes identified by Benton Harbor as known LSLs as of early December, including homes on Smith Court; and, as of documentation available in mid-January 2022, at least 55 of the 215 filter effectiveness sample sites had known LSLs at the time of sampling. Based on a preliminary statistical assessment performed by an EPA contracted statistician, 200 homes were targeted in the sampling pool to answer the question of whether properly certified POU faucet filters and pitcher filters reduce lead to 5 µg/L (5 ppb) (the NSF/ANSI 53 certification standard) or less (estimated number of samples needed to reach a 95% lower confidence bound at 95% confidence).

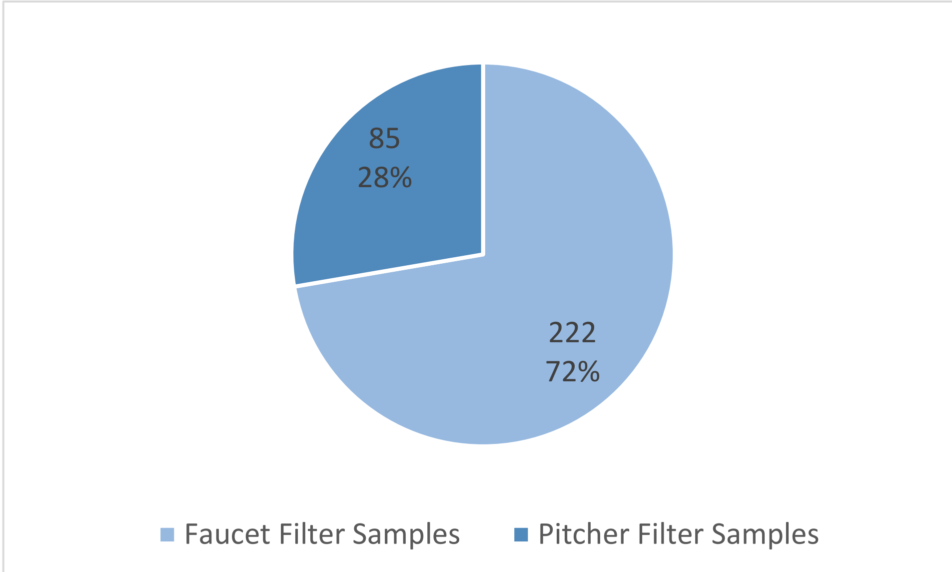


Figure 1. Distribution of faucet POU and pitcher filters sampled in filter effectiveness study.

The filter effectiveness study sampling in Benton Harbor began on November 9, 2021. Seasonality often impacts lead release, and colder temperatures can reduce the amount and rate of lead release, so the study was designed, organized, and started as rapidly as was logistically possible to minimize the effects of the increasingly cold weather.

During the home visit, the sampling team collected information from the residents and observation of the home, including but not limited to details about the service line material, type of filter, operating status of the filter, use of whole house filters/softeners, and water stagnation time. Initially, no special instructions regarding water stagnation time were provided to residents in advance of filter effectiveness sampling. Water samples were collected at random stagnation times (random daytime [RDT] samples) as reported by the residents. After reviewing samples collected in November, it was noted that most of the reported stagnation times were 1 hour or less. Beginning with samples collected on 11/29/21, schedulers encouraged residents to stagnate their water prior to the sampling visit, and all residences scheduled for sampling after 11/29/21 were requested to stagnate their water for 6+ hours prior to the sampling visit to try to increase the challenge of the influent lead level to the filters.

Filter Study Sampling Protocol. The filter effectiveness study was designed to evaluate whether properly certified and operated faucet mounted POU and pitcher filters reduced lead to at or below 5 ppb. For this study, properly operated faucet filters included those that had a green or yellow indicator light when the samples were taken (or were within the total dissolved solids, TDS, operating bounds for the ZeroWater™ filters) and only had cold water run through them. While properly operated filters were only considered in this report, the sampling team tracked inadequately maintained filters (i.e., red or malfunctioning light, hot water was used through the filter, or TDS reading outside of the operating limit), and the water was still sampled through these filters. When compromised filters were used by residents, the EPA sampling team provided filter education to the resident and replaced the filter (following manufacturer instructions). If the faucet POU filter (or pitcher) filter was compromised, the replacement filter was sampled if the newly installed filter cartridge did not require a conditioning step. If a conditioning step was necessary, EPA attempted to schedule a follow-up sampling visit for a later date. All samples were collected without altering the aerators on the faucet.

Faucet Mounted POU Filter Sampling Procedure. First, with the filter in the on position, the cold-water tap was turned on and the first 5 seconds of filtered water was collected in a 500 mL or 250 mL wide-mouth HDPE bottle. This (-5FF##) sample is not considered proper use as, according to the POU filter operation instructions, the first 5 seconds of use is to be wasted; however, this water sample was analyzed for lead (data forthcoming). Immediately following the 5 second flush sample, without turning the water off and taking care not to spill, a 1 L sample of filtered water was collected in a wide-mouth HDPE bottle (-FF##). Next, the filter was switched to bypass mode without turning the water off, and a 1 L sample of unfiltered water was collected (-UF##).

Pitcher Filters Sampling Procedure. Any water that was found to be in the pitcher on sampler arrival was transferred to another container so that the pitcher was completely empty to start. The cold-water tap was turned on, and a first draw 1 L sample (-PF##) was collected in a 1 L HDPE bottle. Immediately following without turning off the water, a second 1 L sample (-UF##) was collected without allowing any water to spill. The first liter of water that was collected (-PF##) was turned "end over end" five times to mix and then poured into the empty pitcher filter. Once the sample passed completely through the filter the filtered water was poured into a new sample bottle for laboratory analysis. Some water poured into the pitcher filter has the potential to be retained within the filter (when the filter is new), so that the volume of pitcher filtered water was slightly less than the influent volume. If the filtered water sample did not have enough volume to reach the 1 L mark on the sample bottle, an additional sample of water was collected and filtered in the pitcher until there was enough effluent to fill the bottle.

Service Line Filter Study Samples. After a review of preliminary data, beginning with samples collected on and after 12/2/21, an additional pair of samples were collected during filter sampling visits. These samples targeted water in contact with the service line that was approximated to be at the 7th liter based on review of past MDHHS sequential profile lead data. The intent was to find higher lead concentrations to challenge the filter by targeting water that had a greater chance to capture the lead contribution directly from known or assumed LSLs (if present). Once the first unfiltered sample (-UF##) was collected, the cold water was allowed to run (if a faucet filter, the filter was in bypass mode) while filling and wasting 1 L sample bottles until 4 L of water had been flushed after the initial two 1 L samples (-FF## or -PF## and then -UF##). Then filtered service line and unfiltered service line samples were collected as described below.

- Faucet Mounted POU Sites: The filter was switched to the on position and the first 5 seconds of filtered water was wasted, then a 1 L service line sample of filtered water was collected (-FFL##). Immediately following the service line (-FFL##) sample, without turning off the water, the filter was switched to bypass mode and a 1 L sample of unfiltered water was collected (-UFL##).
- Pitcher Filter Sites: A 1 L service line sample was collected (-PFL##). Immediately following the service line sample without turning off the water, a second 1 L sample (-UFL##) was collected. The -PFL## sample was then filtered through the pitcher filter as previously described.

Sequential Sampling Protocol. Residents were instructed to flush cold water through the faucet in the intended sampling location for 5 minutes at least 6 hours prior to their scheduled sampling. After the 5-minute flush, residents were instructed to turn off the faucet and not use any water in the house for at least 6 hours prior to sampling. Sequential samples were collected only after the resident verified that water in the entire home had been stagnant for 6+ hours.

The first two sequential samples in the profile were collected in 125 mL HDPE bottles to identify smaller lead containing premise plumbing components near the tap (i.e., faucet and connected plumbing). The rest of the sequential samples were collected in 500 mL HDPE bottles. A 1 L HDPE bottle was included in each set of sequential samples targeting the anticipated highest lead concentration for lead fractionation (particulate). The location of the 1 L sample bottle within the sequential set was predetermined by identifying the location of the peak lead level observed in sequential samples that were previously collected from the homes by MDHHS. The number of sequential sample bottles equated to approximately 16 L per site, unless previous sequential sample results from the residence suggested that a larger or smaller number of samples were necessary to collect water to beyond the service line (fully flushed water from the main).

Bottles were prelabeled and arranged in order on a nearby surface. The cold-water tap was turned on (bypass mode if a faucet POU device was present) so that the first volume of water out of the tap was carefully collected (lower flow rate) in the first sequential sample bottle (125 mL). Immediately following the first sequential sample, without turning the water off and taking care not to spill, the second sample was collected. After the first two 125 mL bottles the flow rate was increased and sampling continued until all bottles allocated for the sampling site were filled.

Once sequential sampling was complete, the cold water was allowed to continue flushing at the maximum flow rate for an additional 5 minutes. After 5 minutes of flushing, three 500 mL HDPE sample bottles were sequentially collected, and temperature was measured (data forthcoming in summer 2022 report). The first flushed sample was analyzed for metals (reported here for lead), the second and third samples were analyzed for background water quality including alkalinity and total organic carbon [TOC] (data forthcoming). Water was also collected and analyzed on-site, if possible, for free chlorine, total chlorine, and alkalinity (alkalinity to be reported later in the summer 2022 report). If field equipment was unavailable, total chlorine, free chlorine and alkalinity were measured at the field office within two hours of sample receipt. Free chlorine levels less than 0.2 mg Cl_2/L were resampled after an additional 5 minutes of flushing. If the sample still contained less than 0.2 mg Cl_2/L free chlorine, the MDHHS member of the sampling team collected a water sample for bacteriologic analysis. (MDHHS was responsible for microbiological analyses (i.e., total coliform and *E. coli*) and reporting results to residents.) Then flow rate was reduced to the width of a pencil and four flasks of water were collected with no headspace; these samples were analyzed for pH in the field laboratory (data to be reported later in the summer 2022 report). Water samples for metals analyses were field preserved with nitric acid to a pH of <2.

Particle Size Fractionation. Sample filtrations and solid sample collection occurred on the 1 L peak-targeted sequential sample as soon as possible (within 2 hours) to reduce the likelihood that metal particulate could continue to change over time. Once back at the field laboratory, the 1 L bottle was turned "end over end" five times to mix before water was used for each of the various filtrations detailed below. For the syringe filtrations, each syringe was rinsed with 5 mL of sample water (rinsed and wasted) before drawing up sample water. Then 50 mL of water from the 1 L sample bottle was filtered through a 0.45 µm syringe filter into a 60 mL sample bottle, to identify the fraction of colloidal Pb (particle size <0.45 µm). This step was repeated from the 1 L bottle with a 0.2 µm syringe filter into a separate 60 mL sample bottle, to determine the nanoparticulate Pb fraction (particle size <0.2 µm). For ultrafiltration the stirred cell has been observed to adsorb some soluble Pb. For this reason, a pre-conditioning step was developed for the stirred cell by filling it with 250 mL of sample water for at least 5 minutes to saturate the stirred cell with Pb. This conditioning water was then wasted, and the cell was refilled with 250 mL of sample water that underwent filtration. This sample water was filtered through a 30 kDa ultrafilter into a 125 mL bottle for laboratory analysis, to determine the soluble fraction of Pb. 30 kDa was determined to correlate with pore sizes smaller than 10 nm. The remaining sample in the 1 L bottle was retained for total metals analysis.

Water analysis. Water samples were analyzed at USEPA Region 5's Chicago Regional Laboratory (CRL). Samples were analyzed for lead using EPA method 200.8 (CRL Standard Operating Procedure for the analysis of metals by Inductively Coupled Plasma-Mass Spectrometry, EPA method 200.8/SW-846

6020B using the Agilent 7700x, Metals 001 version 11). The reporting limit for Pb from CRL is 0.5 ppb. In accordance with the target minimum of one per 20 samples, over 100 field blanks were collected, associated with the approximately 1,800 field samples for metals analysis. Field blanks were filled with Milli-Q® water (lab distilled water that is passed through a mixed bed resin column before use) at the field laboratory, capped and taken out to sampling sites. During the sampling visit, the field blank bottle was uncapped and left open in the sampling location during sampling. Once all samples had been collected the bottle was capped and placed in the cooler and subsequently field-preserved with the rest of the samples. The data was validated against the laboratory and field performance requirements, before data analysis was performed. Free and total chlorine were measured using a Hach (Hach Company, Loveland, CO) SL1000 portable parallel analyzer according to Hach Method 10260 (EPA approved DPD (N, N-diethyl-p-phenylenediamine) method).

QUALITY ASSURANCE SUMMARY

This study adhered to the following Quality Assurance Project Plans (QAPP), prepared, and approved prior to sampling and updated as necessary over the course of the study:

Benton Harbor, MI Filter Performance Screening and Assessment Study (CESER QA Tracking ID: K-WID-0033382-QP-1-0)

SAMPLING PROTOCOL

This study followed the sampling procedures outlined in:

Drinking Water Sampling Protocols for Benton Harbor Water Study, Version 2.5 12/10/21

Multiple edits were made to the sampling protocol to address matters in the field and are captured in the version history at the beginning of the document.

SUMMARY OF RESULTS

Filter Effectiveness Study. The filter effectiveness study consisted of water samples collected from 199 homes with properly operated filters in Benton Harbor. In total, 306 pairs of filtered and unfiltered water samples and 1 unpaired filtered water sample (corresponding unfiltered sample was accidently discarded) were collected (Appendix A).

Lead concentrations in unfiltered water samples at properly operated filter study homes ranged from below the laboratory lead reporting limit (< 0.5 ppb) to a maximum level of 77 ppb. Twenty-one percent (63 water samples) of the unfiltered water samples contained lead between 5 ppb and 77 ppb and 46% (141) of the unfiltered samples were between 0.5 ppb and 4.99 ppb.

Thirty-three percent (102) of the unfiltered samples were below the reporting limit for lead (Figure 2).

The lead concentrations in all filtered water samples were below the NSF/ANSI 53 certification standard of 5 ppb, and no filtered water lead concentration was greater than 2.5 ppb. Most filtered water samples (90%, 277 samples) were below the reporting limit for lead (<0.5 ppb). Furthermore, 95% of the samples (291) were below 1 ppb, and 5% of the samples (16) were between 1 ppb and 2.5 ppb (Figures 2 and 3).

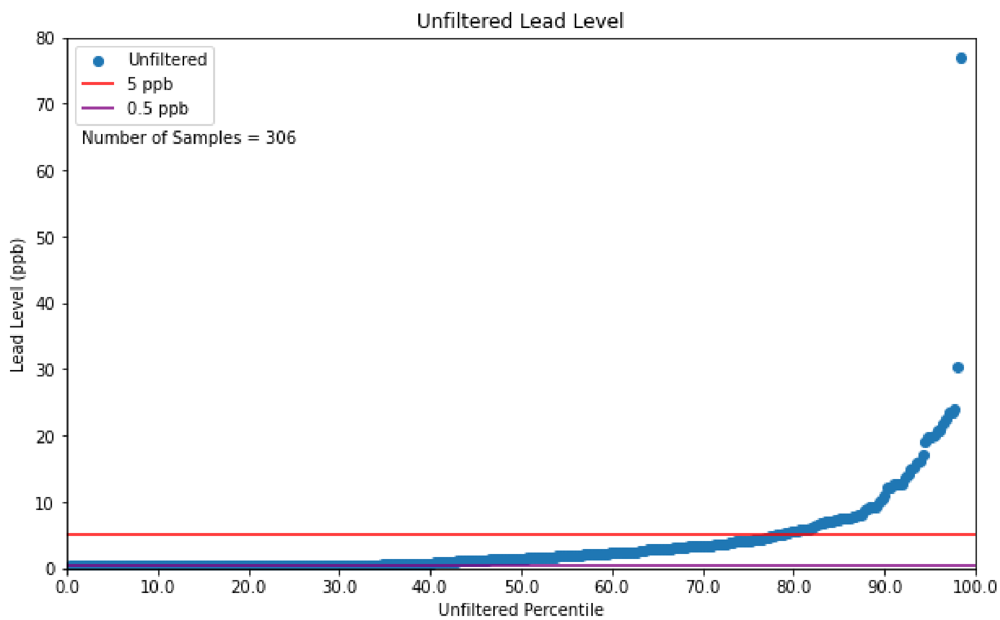


Figure 2. Unfiltered lead levels in water from properly operated filter study homes in Benton Harbor.

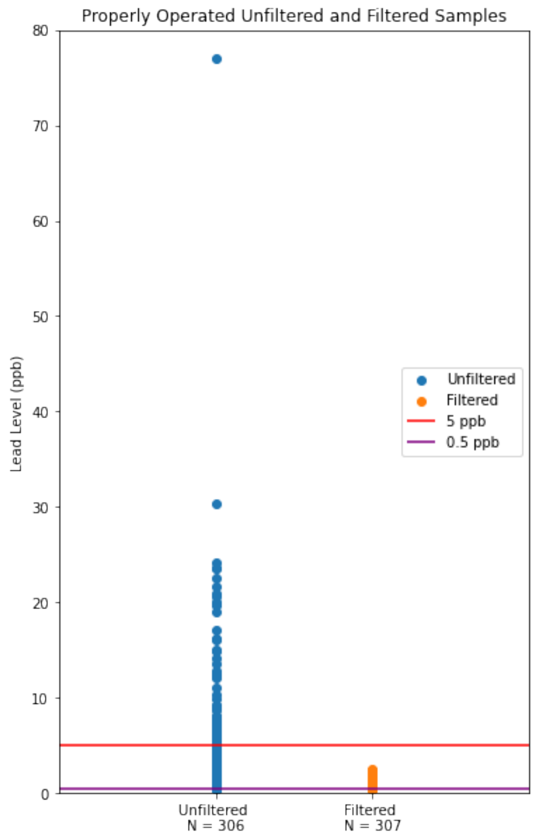


Figure 3. Summary of lead levels in filtered and unfiltered water samples collected at properly operated filter study Benton Harbor homes.

Sequential Profile Study. Sequential profile datasets were collected from 26 Benton Harbor homes (see Appendix B). Profiles varied widely and reflected the unique plumbing configurations and make-up of materials within the home plumbing and service lines. The maximum peak (many profiles had more than one peak) lead concentration in the profiles ranged between about 3 to 391 ppb, and the median maximum concentration was 15 ppb (Figure 4). Three of the profiles had maximum lead concentrations below 5 ppb. Maximum lead profile concentrations clustered around 1 to 3 L and 6 to 11 L (Figure 5). The minimum lead profile concentrations ranged between below the reporting limit (0.5 ppb) and 10.5 ppb. The weighted average lead concentration was determined by dividing the sum of the lead mass of all samples in a profile by the sum of water sample volume of all samples collected in the profile. The weighted average lead concentrations across the entire profile ranged between 0.6 ppb and 31 ppb and the median weighted average value was 6.3 ppb (Figure 4) reflecting the location of different lead sources in the drinking water in the lead-containing premise plumbing material and through the service lines. The first draw 1L equivalent is calculated from the profile as follows: SS01/0.125+SS02/0.125+SS03/0.5+SS04/0.25. First draw 1L equivalent concentrations ranged between 1.9 ppb and 188 ppb, and the median was 5.6 ppb.

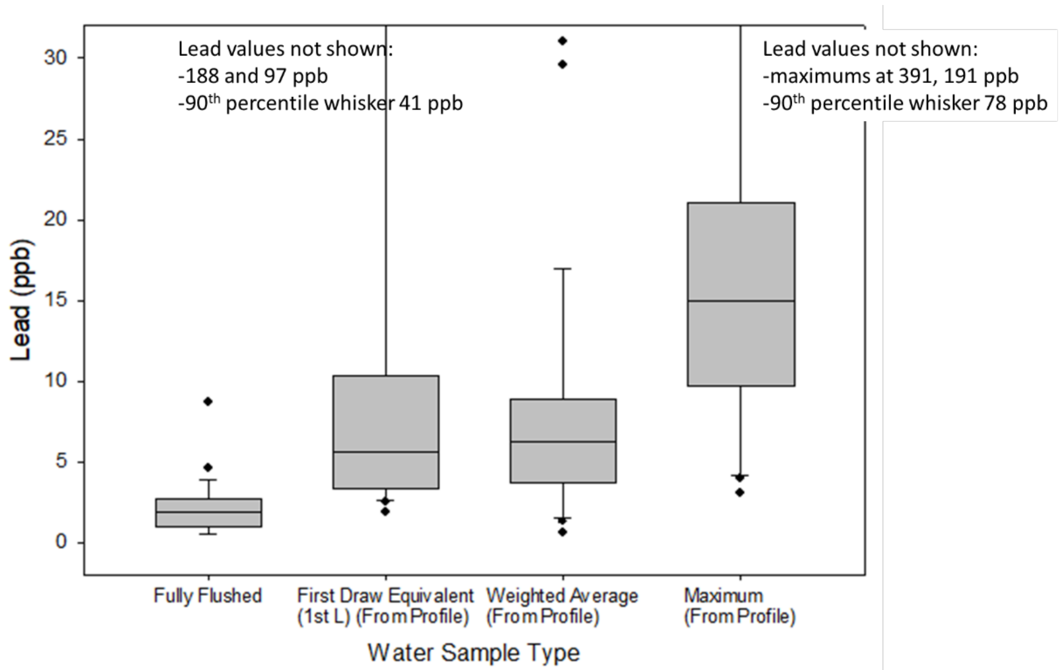


Figure 4. Summary of profile data (26 profiles). Boxes represent the median, and 25th and 75th percentiles. Error bars (whiskers) are displayed at the 10th and 90th percentiles. Dots are data that fall outside of the 10th and 90th percentiles.

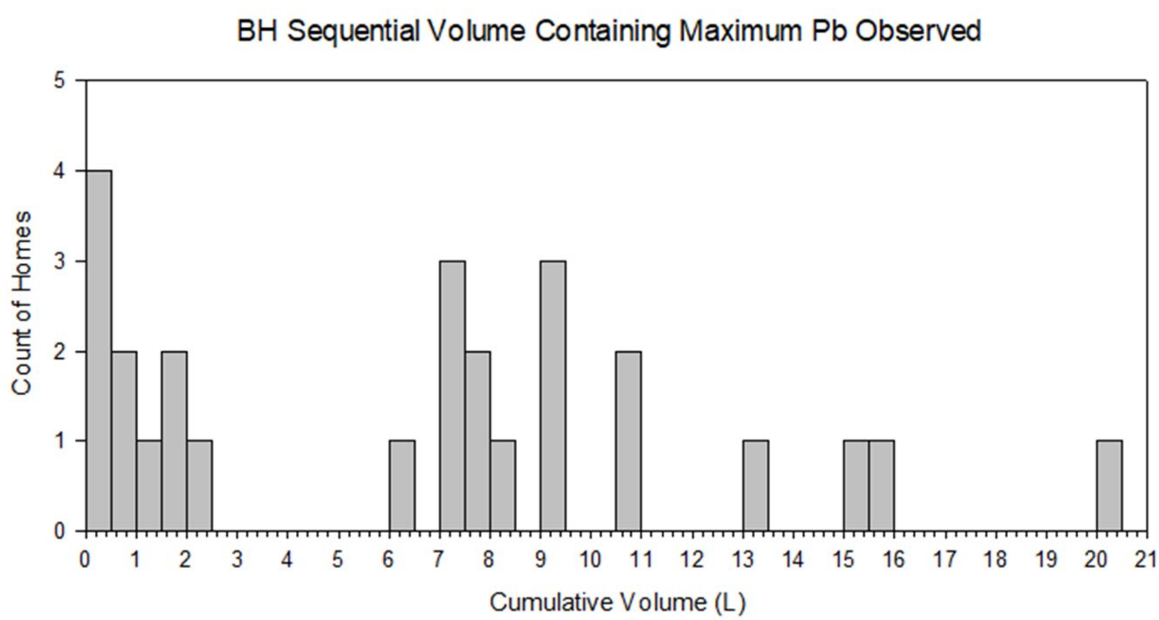


Figure 5. Location (Liter, L) where maximum lead concentration appears in profile.

Lead Particle Size Fractionation Study. Lead size fractionations by filtration (0.45 µm and 0.2 µm filtrations, and ultrafiltration) were performed on water samples that targeted volumes of water with previous high lead concentrations in 16 of the sequential profile sets (homes). Early in the study, a lead field analyzer test kit was used to screen these targeted volumes and filtrations were not performed unless a sample tested ≥9.5 ppb lead. While the field analyzer remained in use, the trigger level for filtrations was removed for samples collected on and after 11/23/21 (after review of preliminary ICP-MS lead data that indicated the field analyzer was reading some sample concentrations low). Lead concentrations in the unfiltered targeted samples ranged between 5 and 133 ppb (median concentration was 14 ppb), and there was no apparent difference between the amount of lead passing different filter sizes (0.45 µm, 0.2 µm, ultrafilter) in any of the samples. The fraction of lead in the particulate form based on ultrafiltered lead results ranged between 15 and 95% (median 37%). Lead particle size fractions indicated by filter fractionization analyses are not necessarily reflective of individual lead particle sizes. Particle-particle interactions, particle interactions with filter surfaces and other factors can impact filter fractionization observations. Additional complementary electron microscopy lead particle analysis will be reported later in the summer 2022 report.

Chlorine Analyses. Free and total chlorine water analyses were performed at 236 Benton Harbor homes (two locations had no recorded measurements). Free and total chorine results ranged between 0.03 and 3.3 mg Cl_2/L and 0.1 and 3.6 mg Cl_2/L, respectively (see Appendix C). Ten homes had free chlorine levels <0.2 mg Cl_2/L in the first 5-minute flushed sample and 8 of those homes still contained <0.2 mg Cl_2/L after an additional 5-minute flush.

CONCLUSIONS

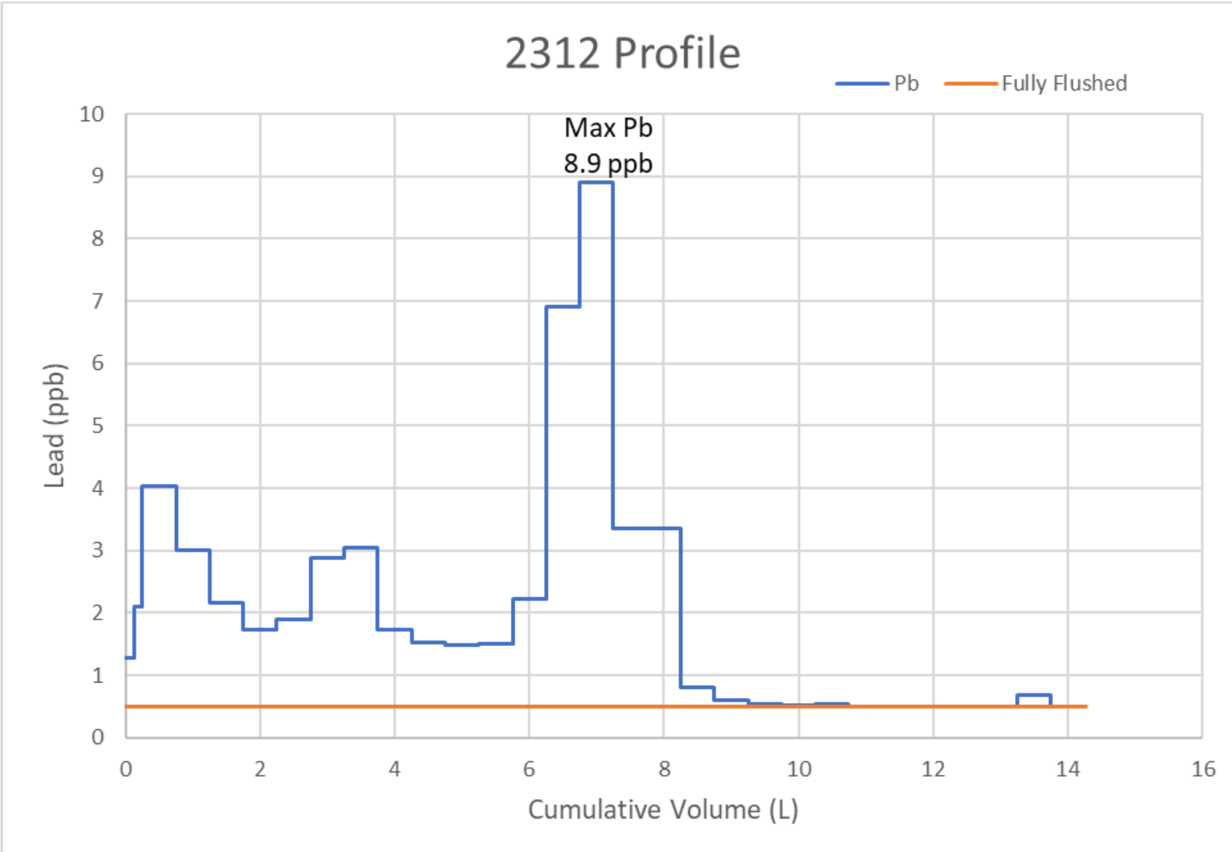
All properly operating filter water samples were found to be below the NSF/ANSI 53 and bottled water certification (21 C.F.R. § 165.110) requirements of 5 ppb lead (FDA). Despite EPA efforts to challenge water filters by targeting LSL homes and efforts in the latter portion of the study to increase stagnation time, lead concentrations in associated unfiltered water samples were also often found to be low in the homes sampled, with 79% of unfiltered water samples containing <5 ppb lead. Higher lead levels were observed in stagnated samples at many sequential sampling locations. Multiple peaks of lead were noted in many of the homes profiled, indicating more than one significant source of lead to household drinking water. There appeared to be two relative clusters where the highest lead levels in the profile samples appeared. One cluster was in the premise plumbing near the tap (1^{st}-3^{rd} liter) and another appeared in the volumes likely representing the service line in the range of the 6^{th} to 11^{th} liter. Additional analyses and other information collected will be reported in a more comprehensive report in summer 2022 which will allow for a more complete analysis and development of broader conclusions.

APPENDIX A

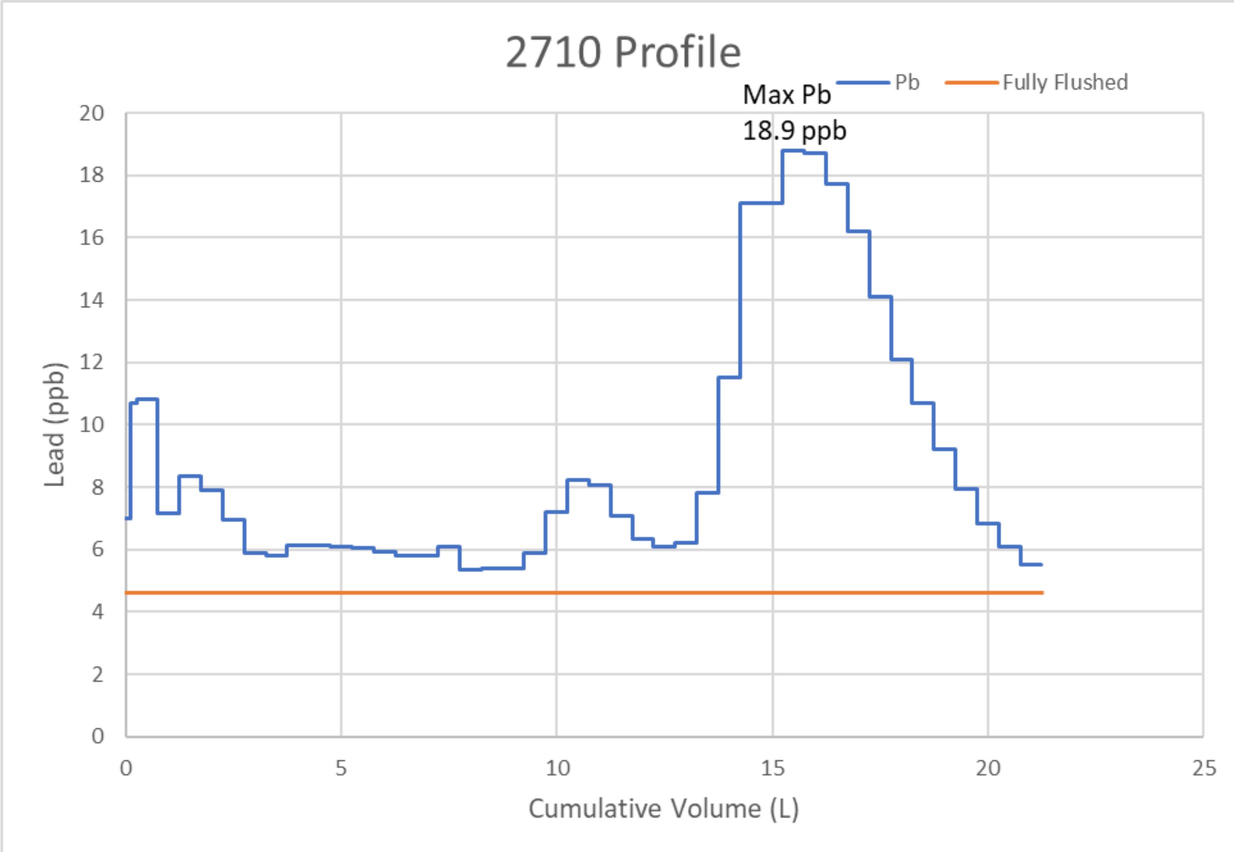
BH_Data_Package_2_7_22_V2.xlsx

Excel Sheet Containing Properly Operating Filter Study Data

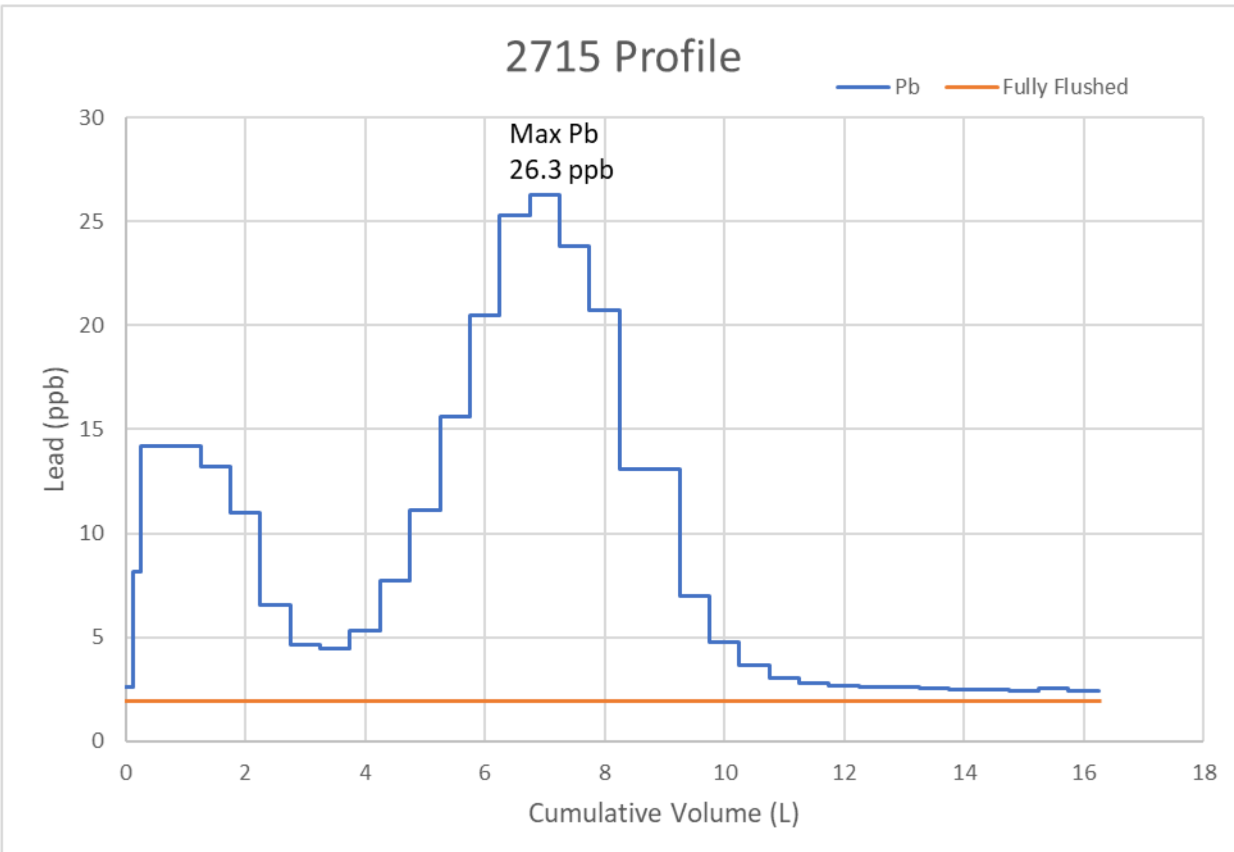
APPENDIX B



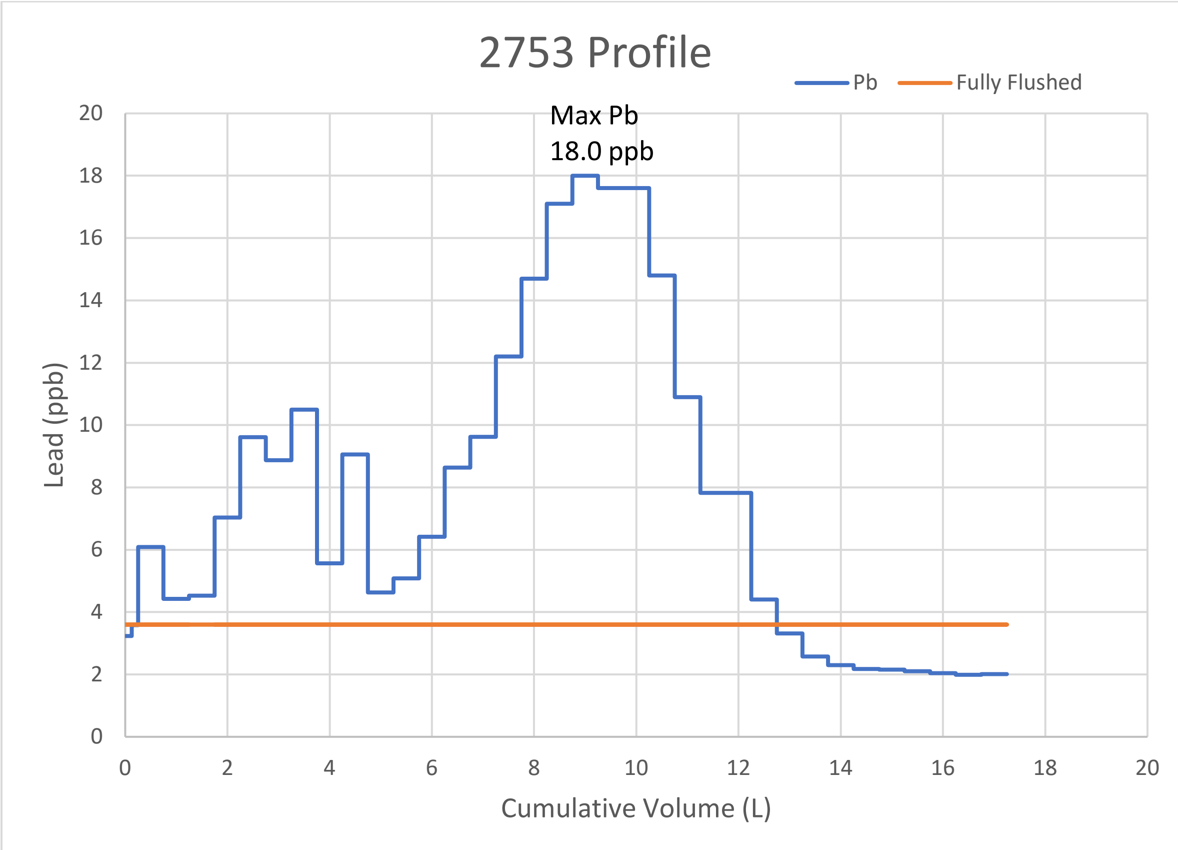
2312 Profile
Pb
Fully Flushed
Max Pb
8.9 ppb
Lead (ppb)
Cumulative Volume (L)
10
9
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
12
14
16



2710 Profile
Max Pb
18.9 ppb
Pb
Fully Flushed
Lead (ppb)
Cumulative Volume (L)



2715 Profile
Max Pb
26.3 ppb
Pb
Fully Flushed
Lead (ppb)
Cumulative Volume (L)


2753 Profile
Pb
Fully Flushed
Max Pb
18.0 ppb
Lead (ppb)
Cumulative Volume (L)
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2
4
6
8
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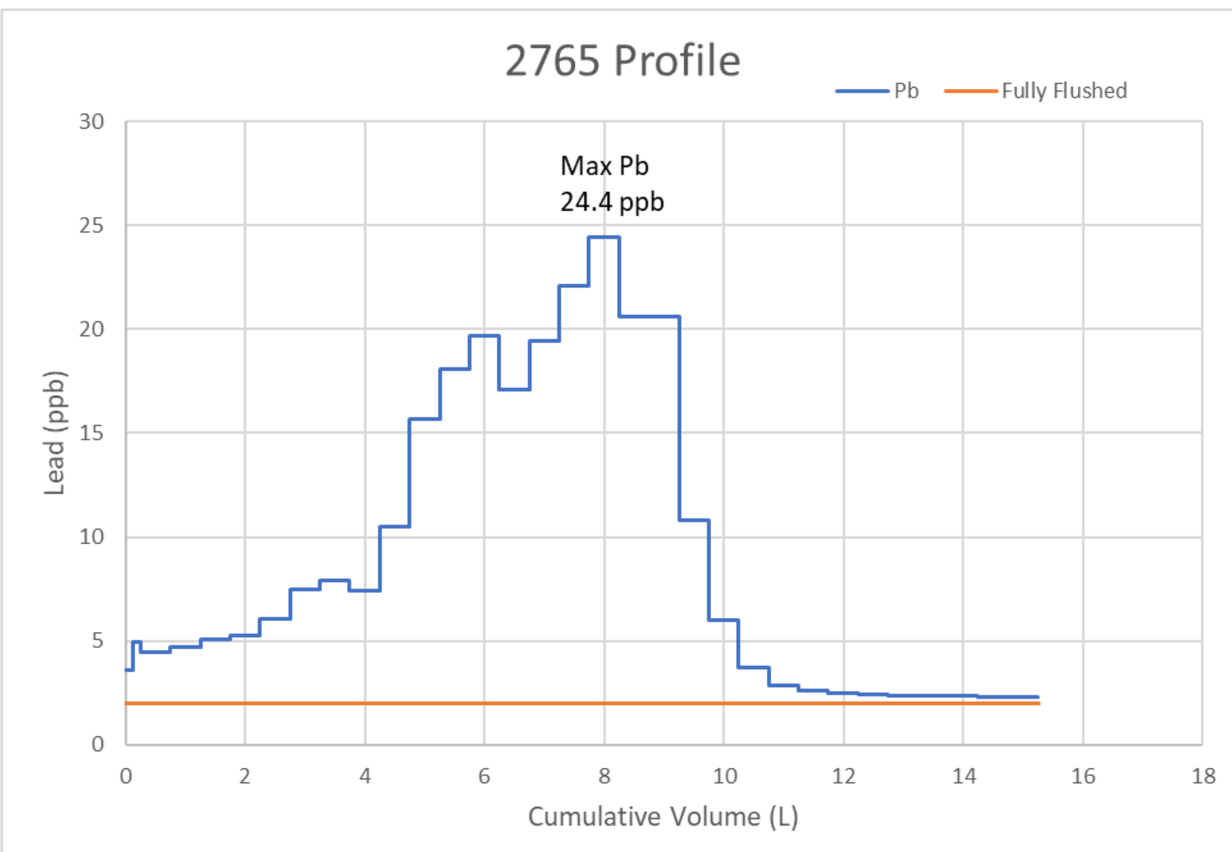
12
14
16
18
20


2765 Profile
Pb
Fully Flushed
Max Pb
24.4 ppb
Lead (ppb)
Cumulative Volume (L)
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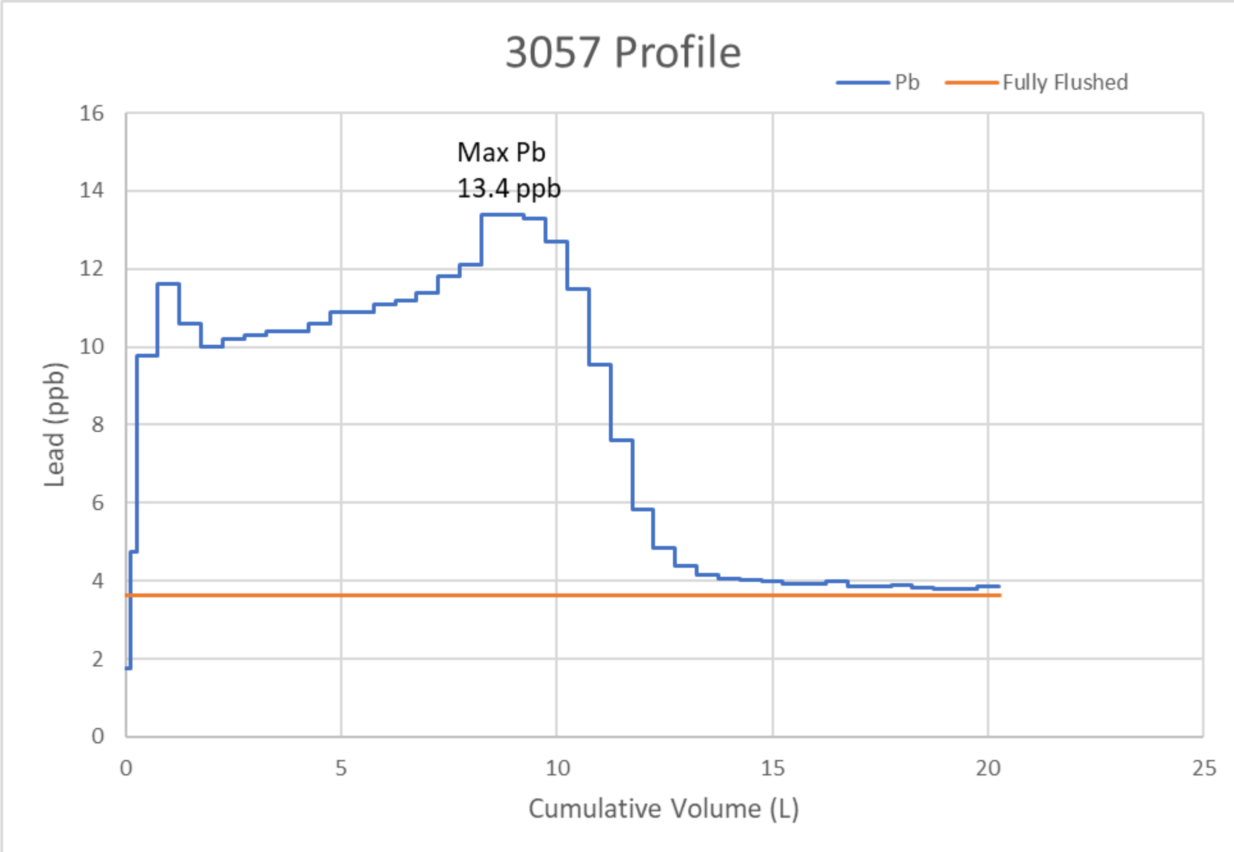
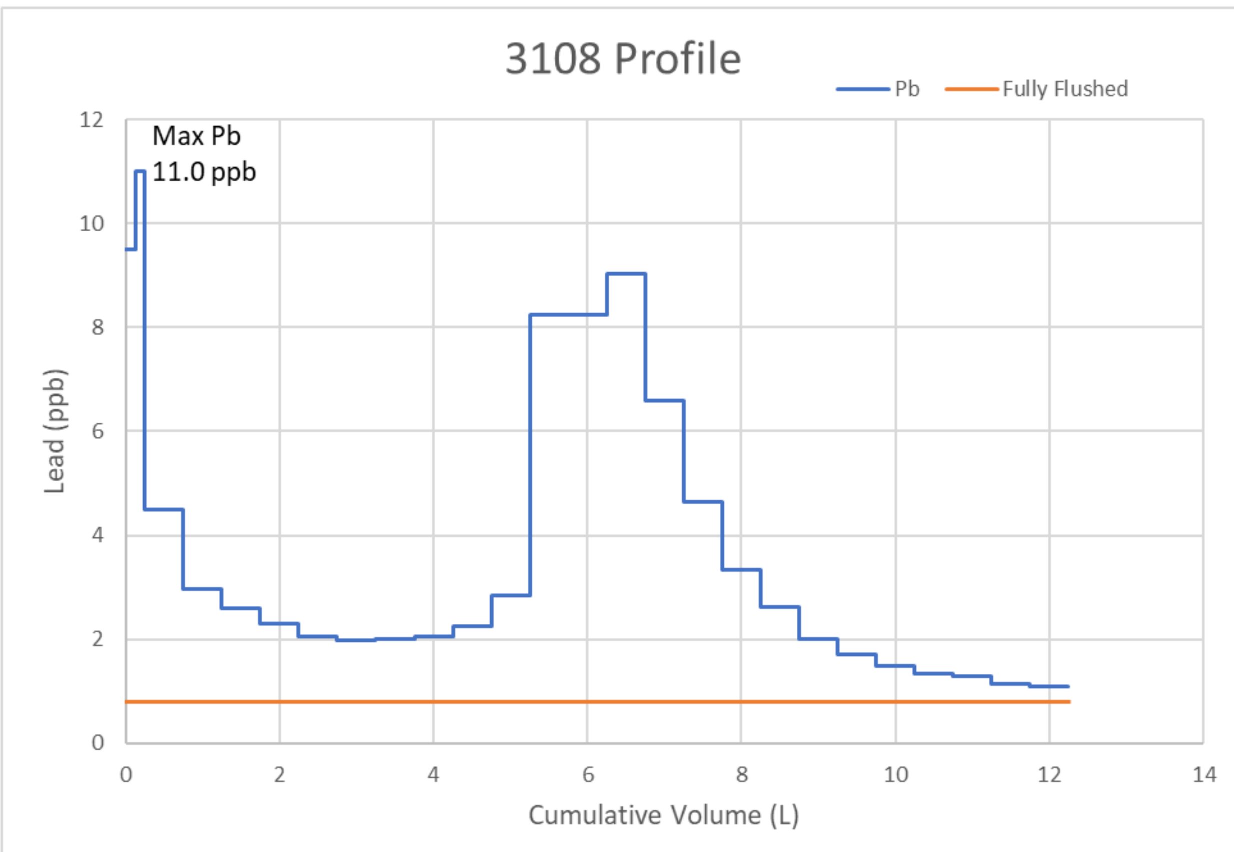
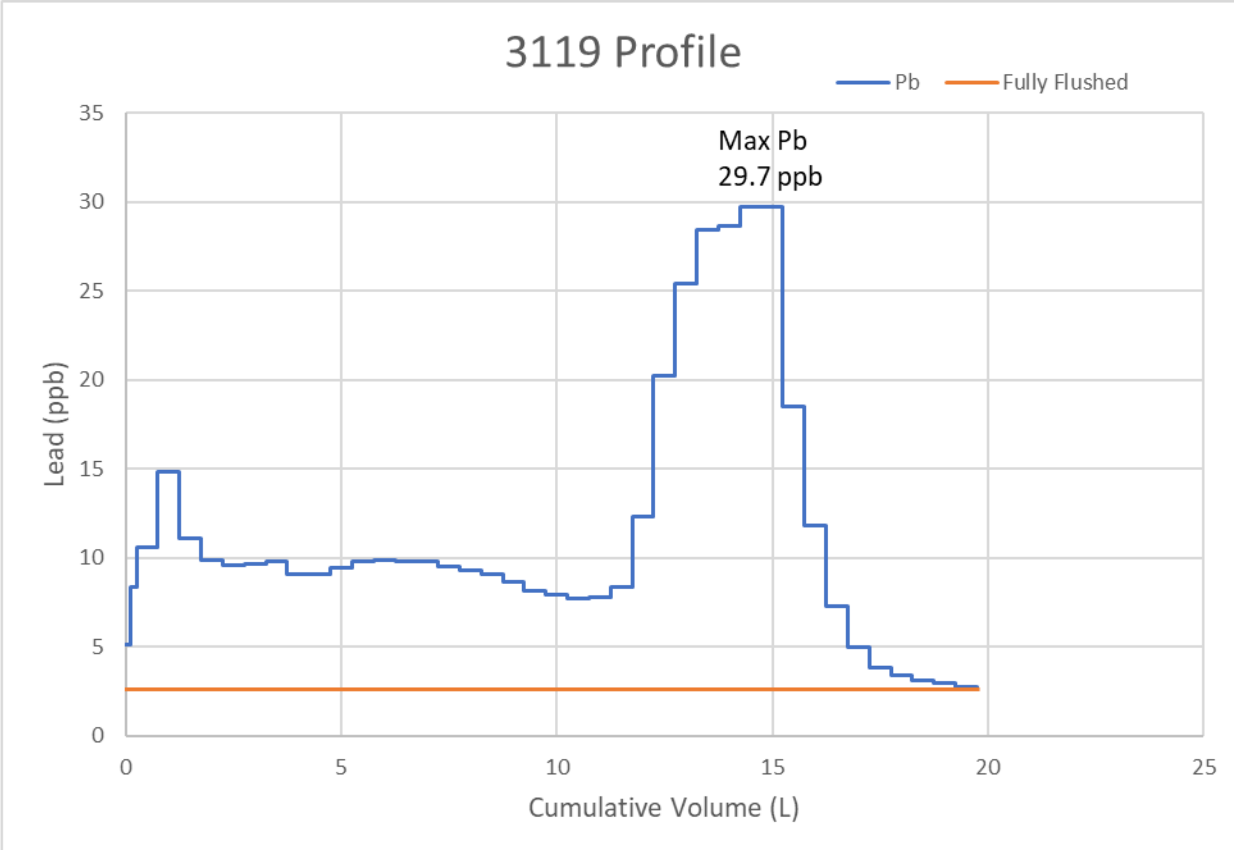
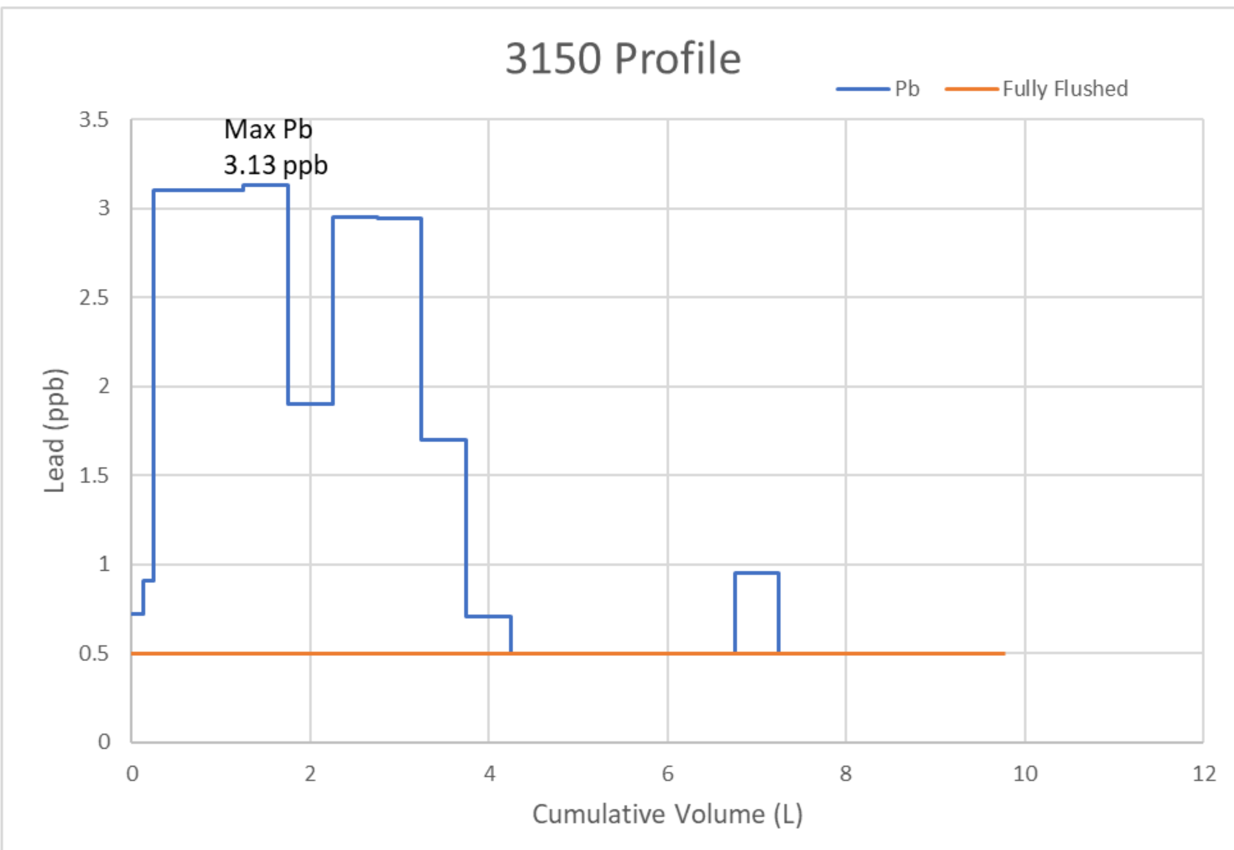
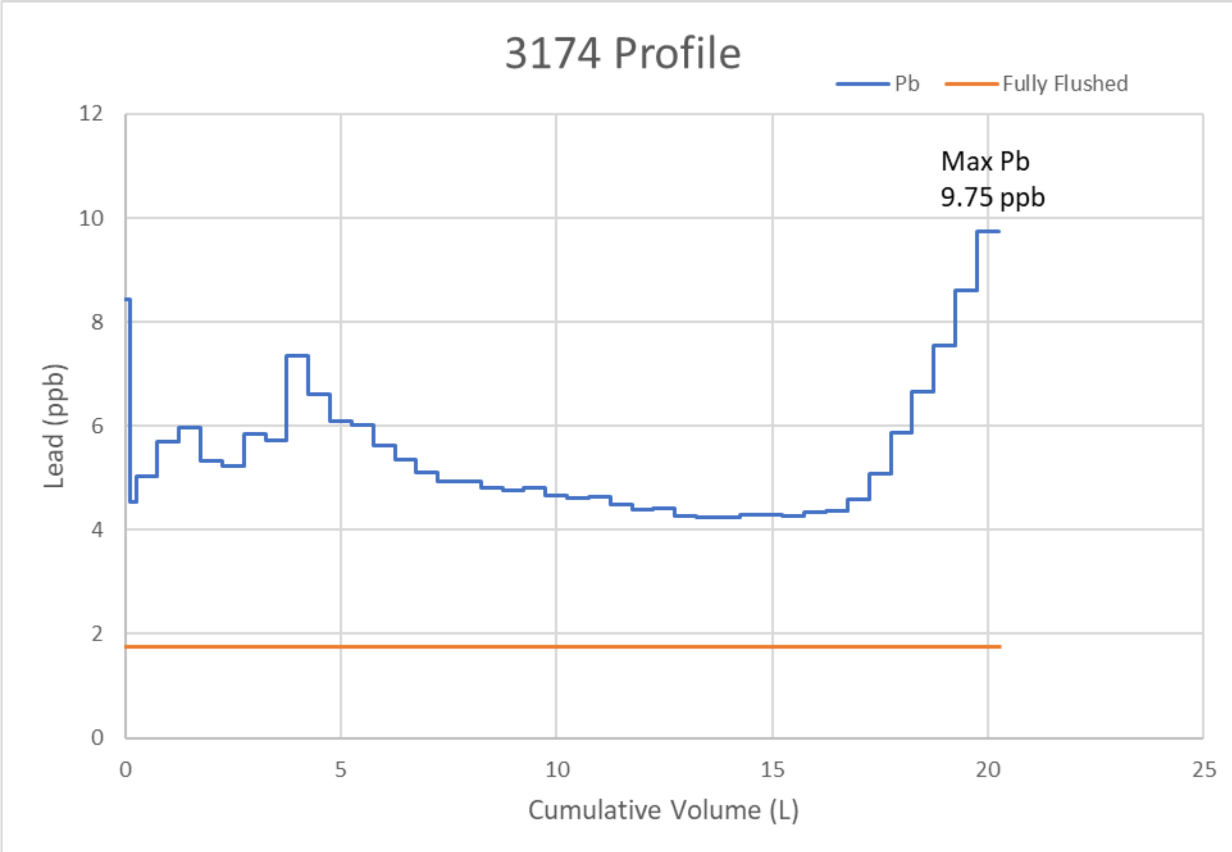
10
15
20
25
30
2
4
6
8
12
14
16
18

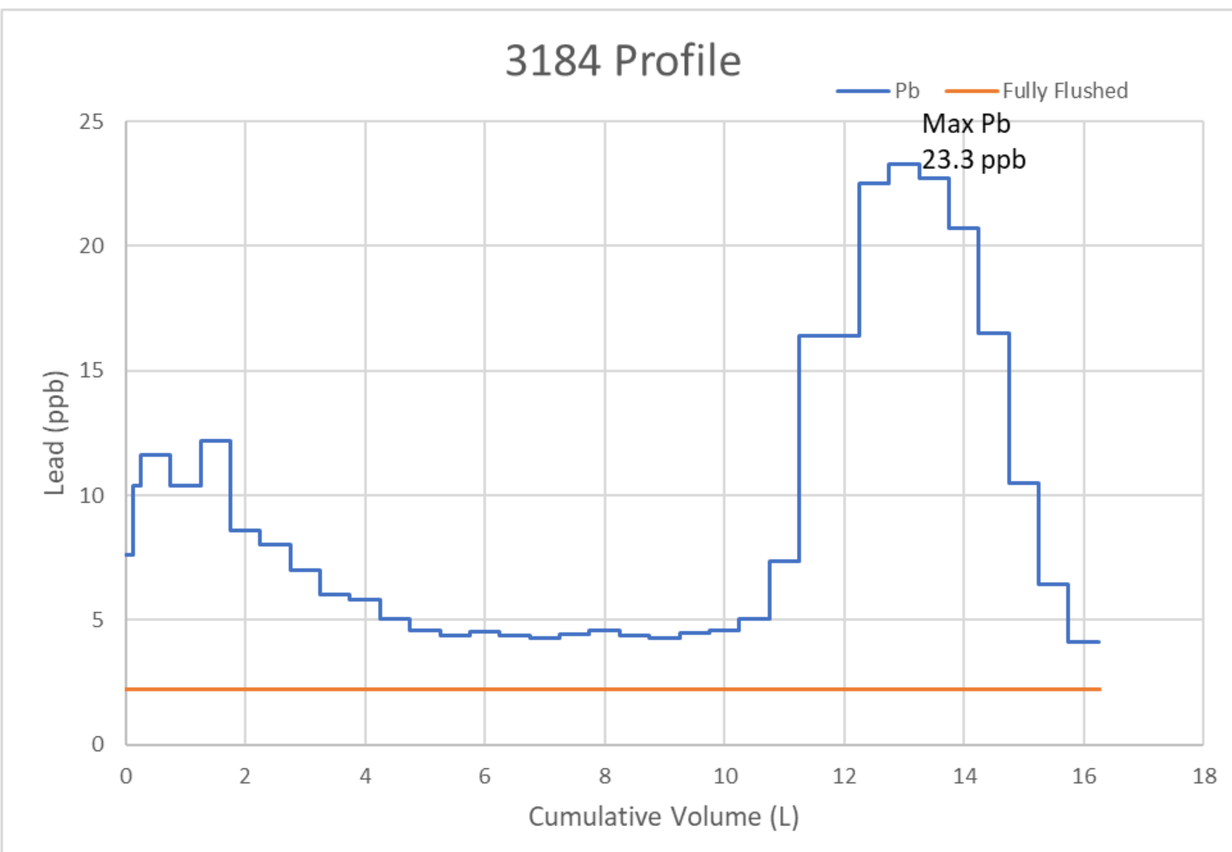

3057 Profile
Pb
Fully Flushed
Max Pb
13.4 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25

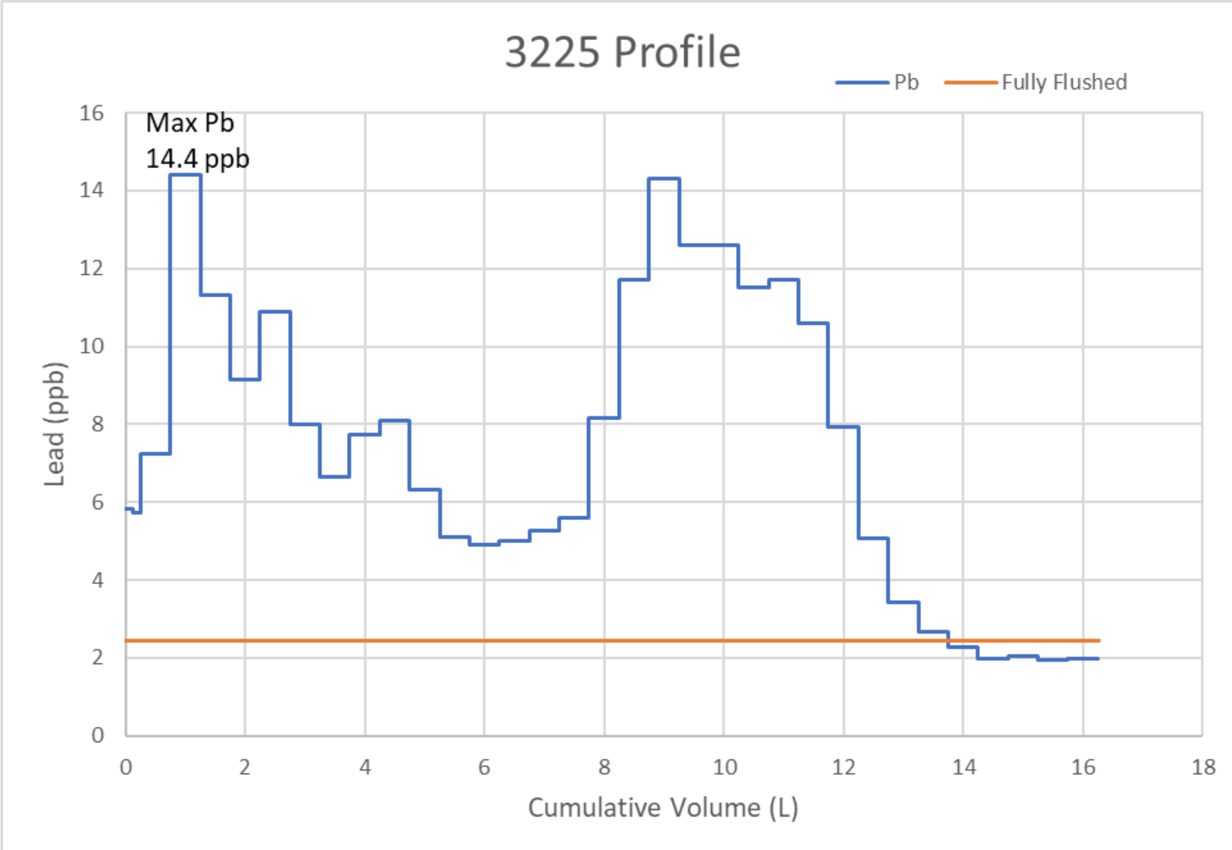

3108 Profile
Pb
Fully Flushed
Max Pb
11.0 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
0
2
4
6
8
10
12
14

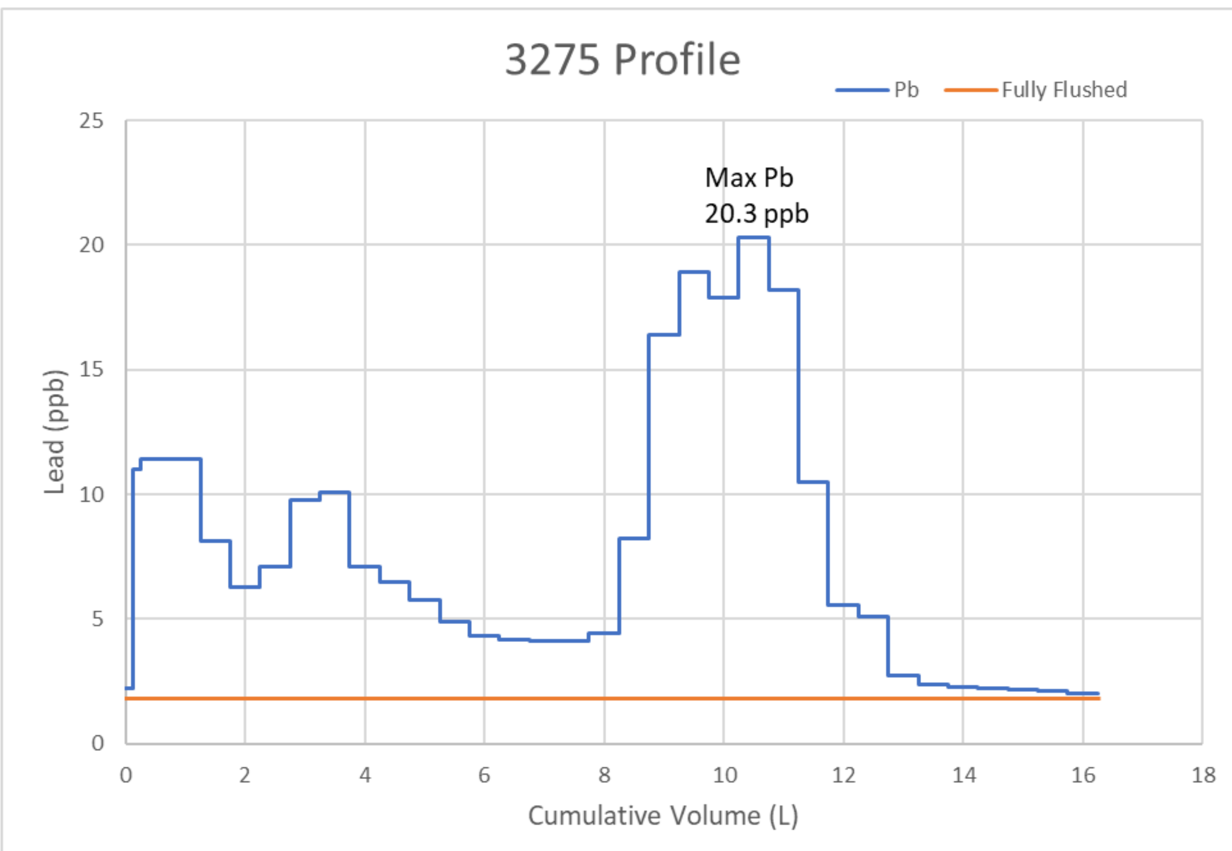

3119 Profile
Pb
Fully Flushed
Max Pb
29.7 ppb
Lead (ppb)
35
30
25
20
15
10
5
0
0
5
10
15
20
25
Cumulative Volume (L)

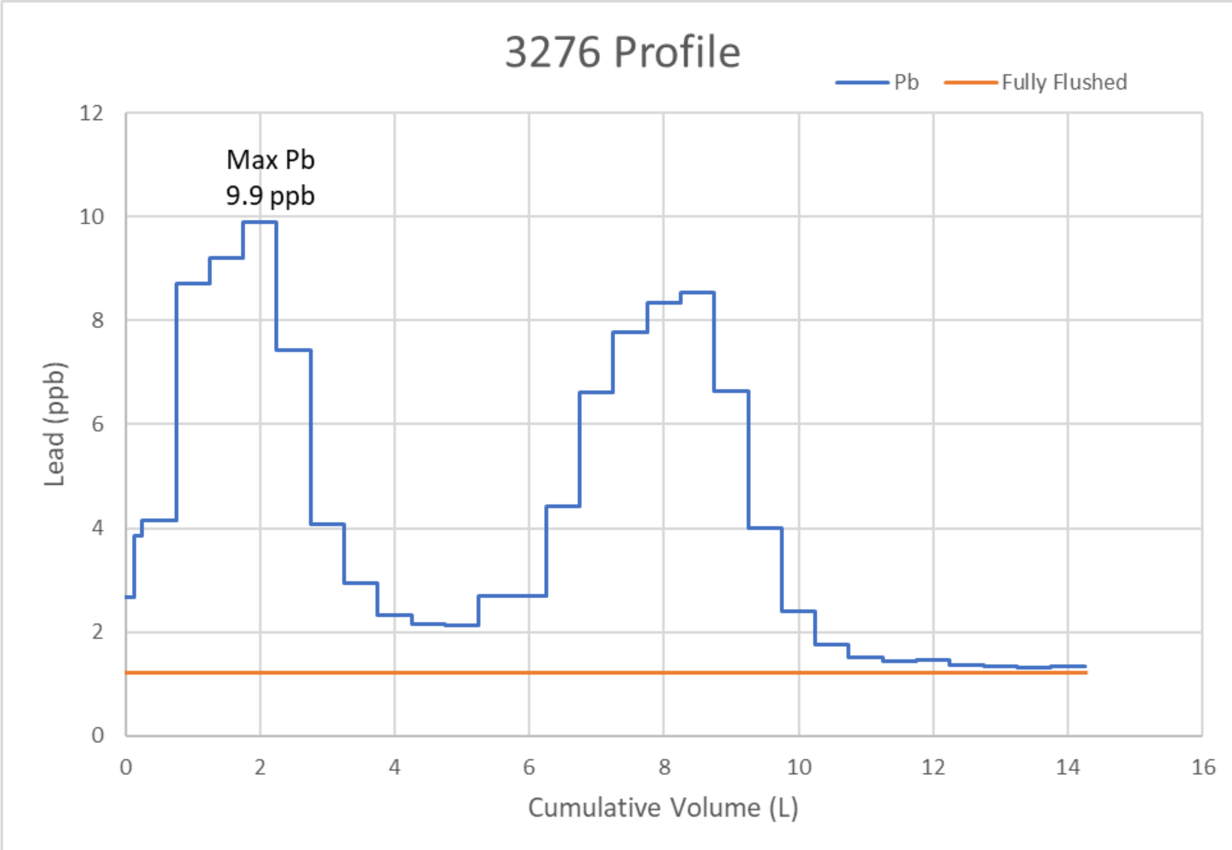

3150 Profile
Pb
Fully Flushed
Max Pb
3.13 ppb
Lead (ppb)
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Cumulative Volume (L)

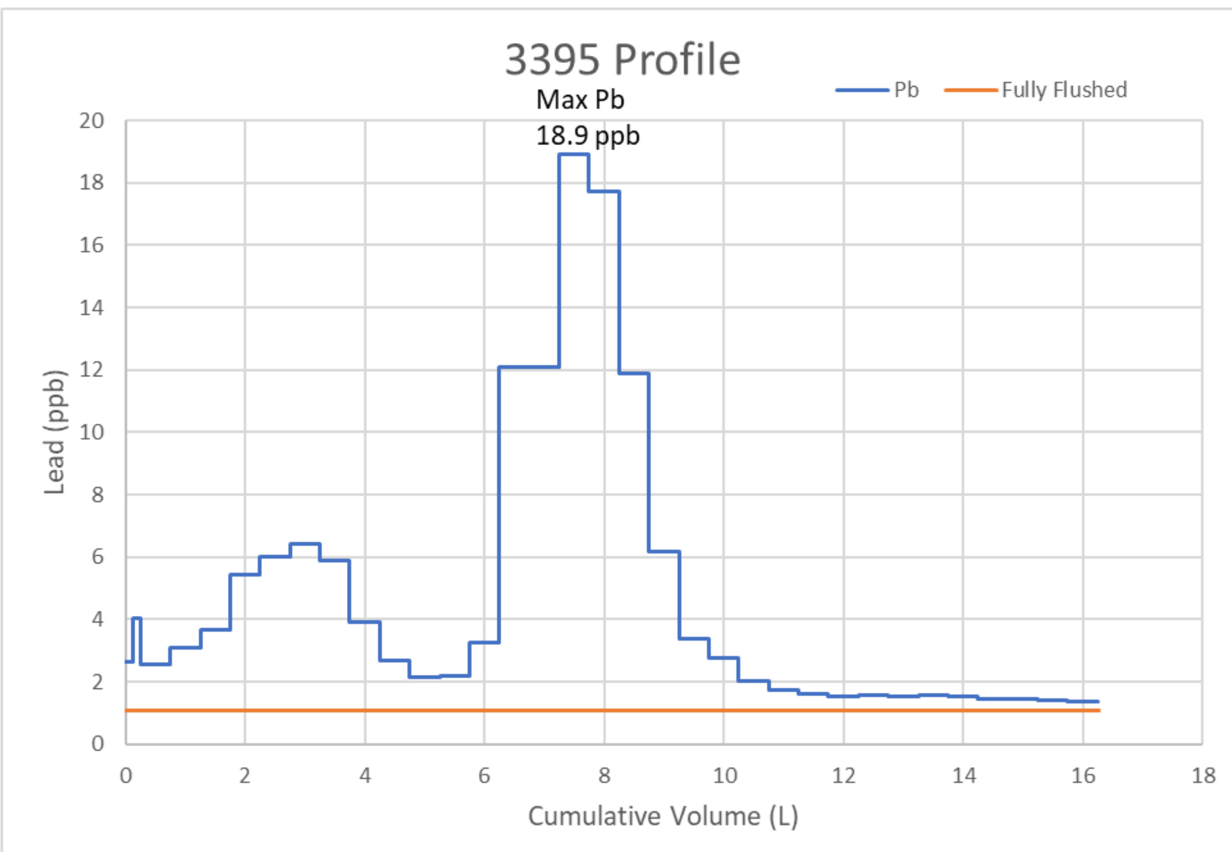

3174 Profile
Pb
Fully Flushed
Max Pb
9.75 ppb
Lead (ppb)
12
10
8
6
4
2
0
0
5
10
15
20
25
Cumulative Volume (L)

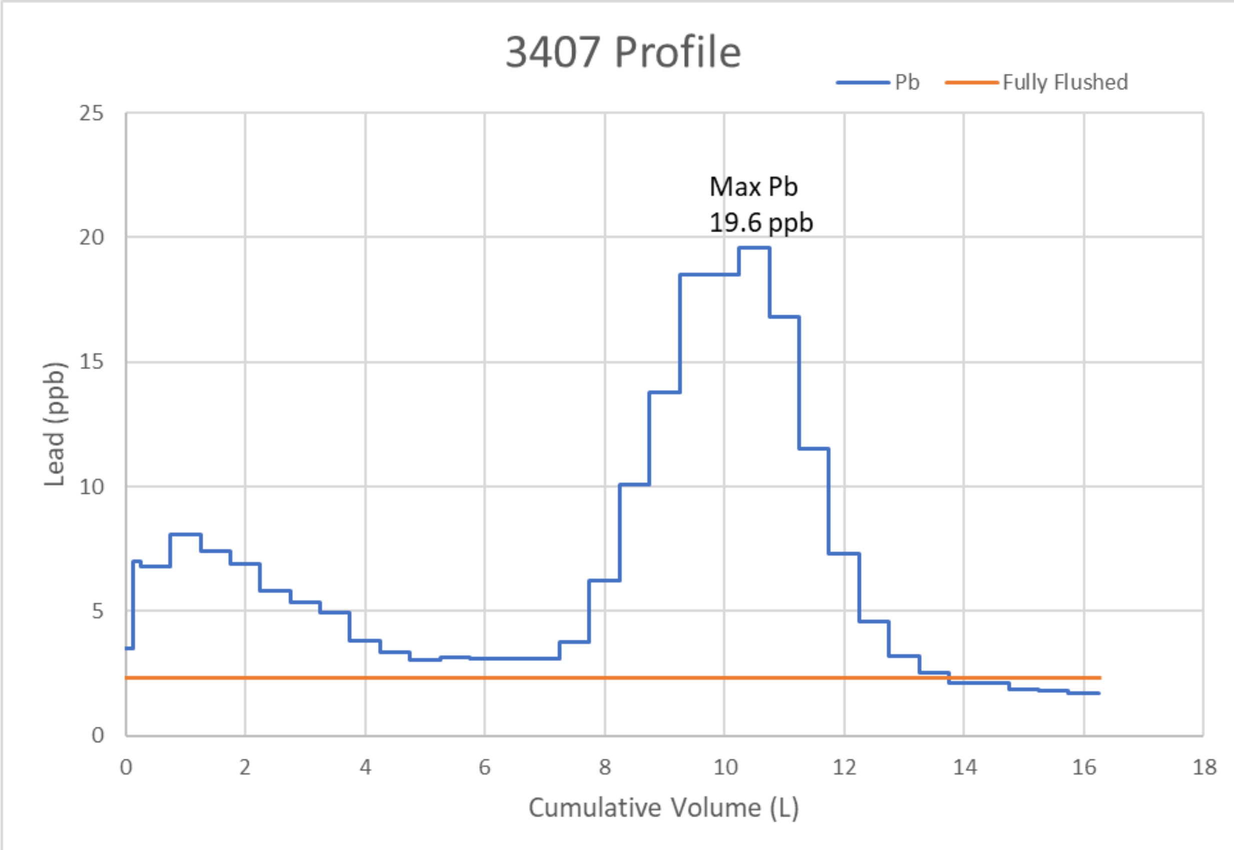

3184 Profile
Pb
Fully Flushed
Max Pb
23.3 ppb
Lead (ppb)
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
Cumulative Volume (L)

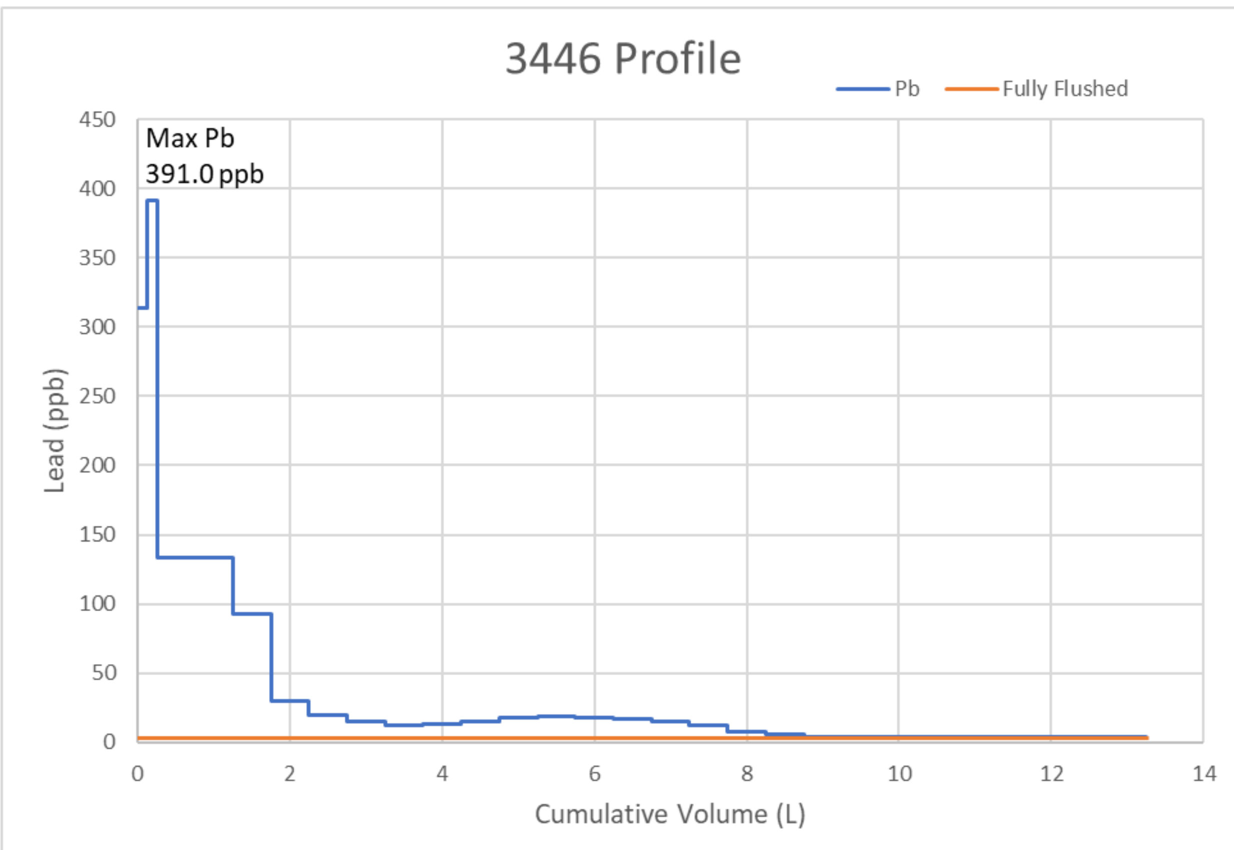

3225 Profile
Pb
Fully Flushed
Max Pb
14.4 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
14
16
18

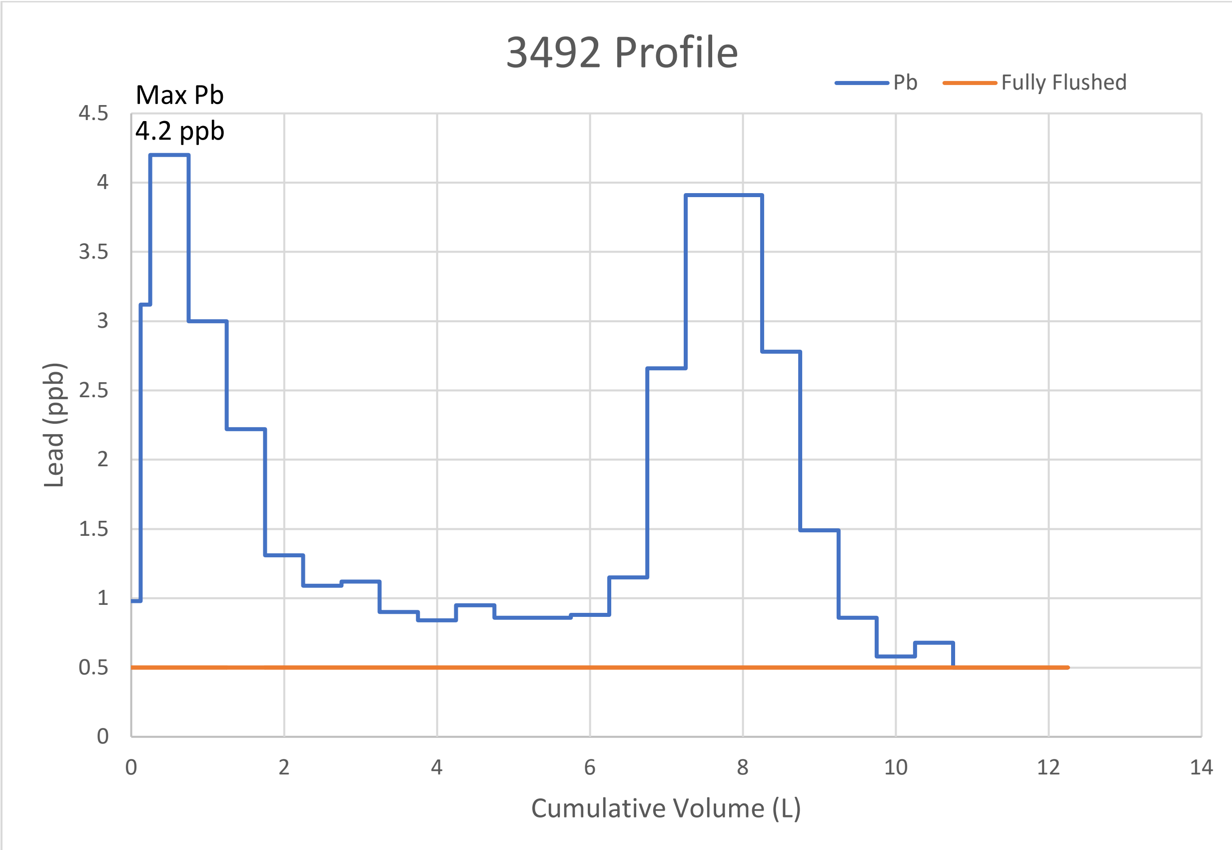

3275 Profile
Pb
Fully Flushed
Max Pb
20.3 ppb
Lead (ppb)
Cumulative Volume (L)
0
5
10
15
20
25
0
2
4
6
8
10
12
14
16
18


3276 Profile
Pb
Fully Flushed
Max Pb
9.9 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
14
16

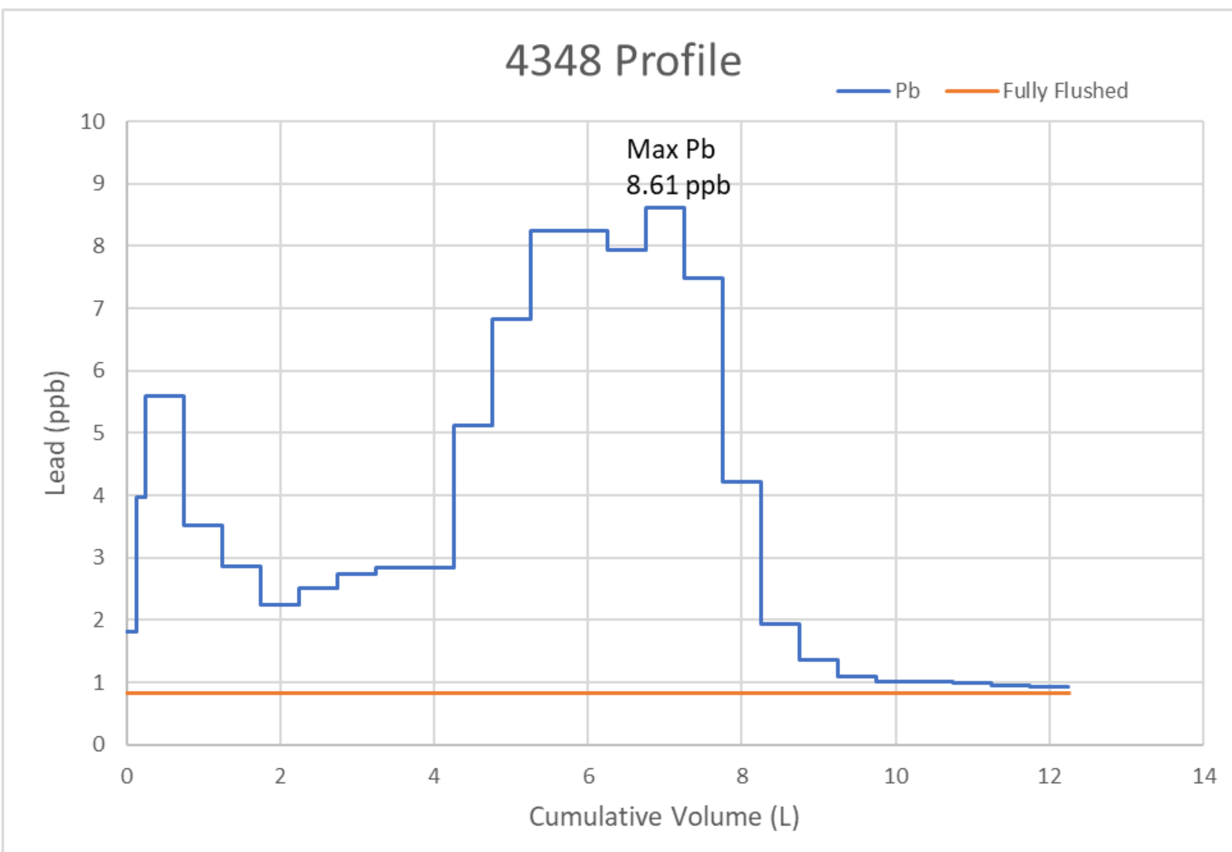

3395 Profile
Pb
Fully Flushed
Max Pb
18.9 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
14
16
18
20


3407 Profile
Pb
Fully Flushed
Max Pb
19.6 ppb
Lead (ppb)
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
Cumulative Volume (L)

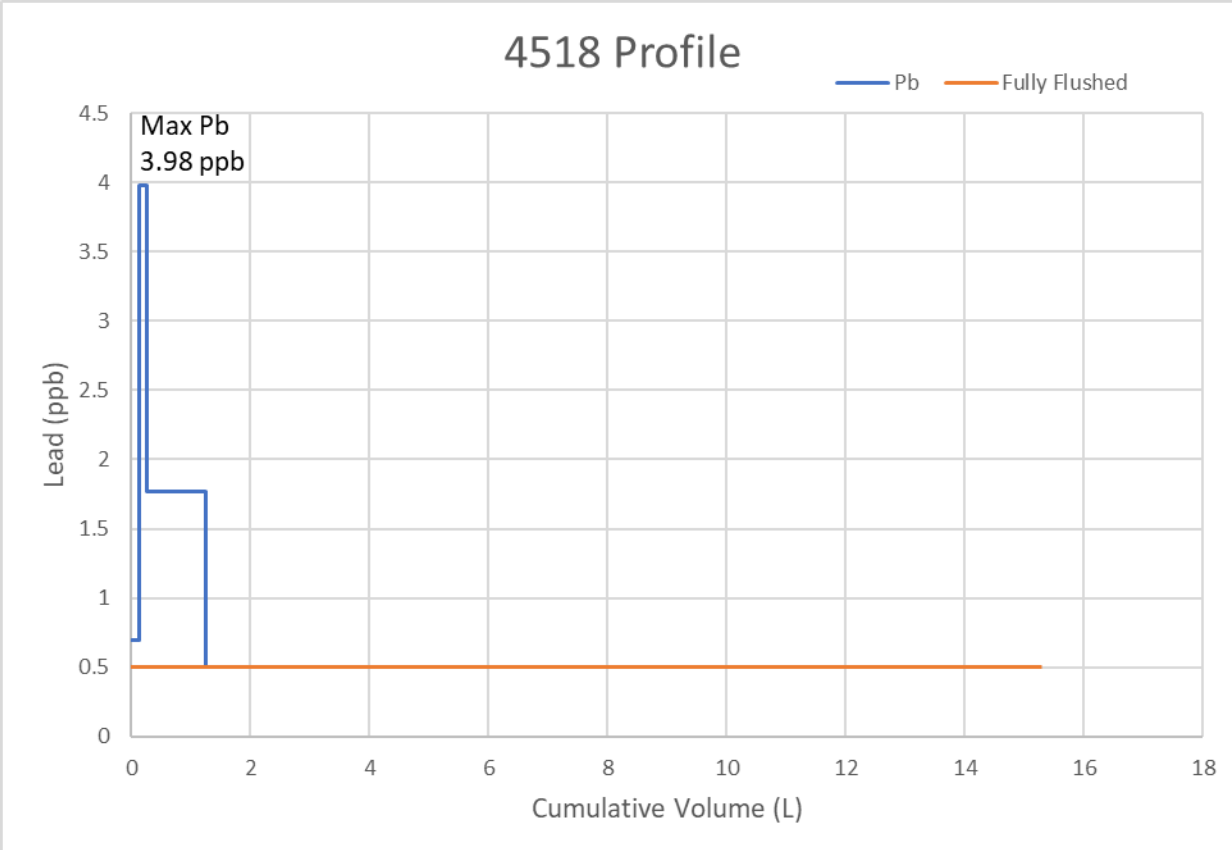

3446 Profile
Pb
Fully Flushed
Max Pb
391.0 ppb
Lead (ppb)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
Cumulative Volume (L)



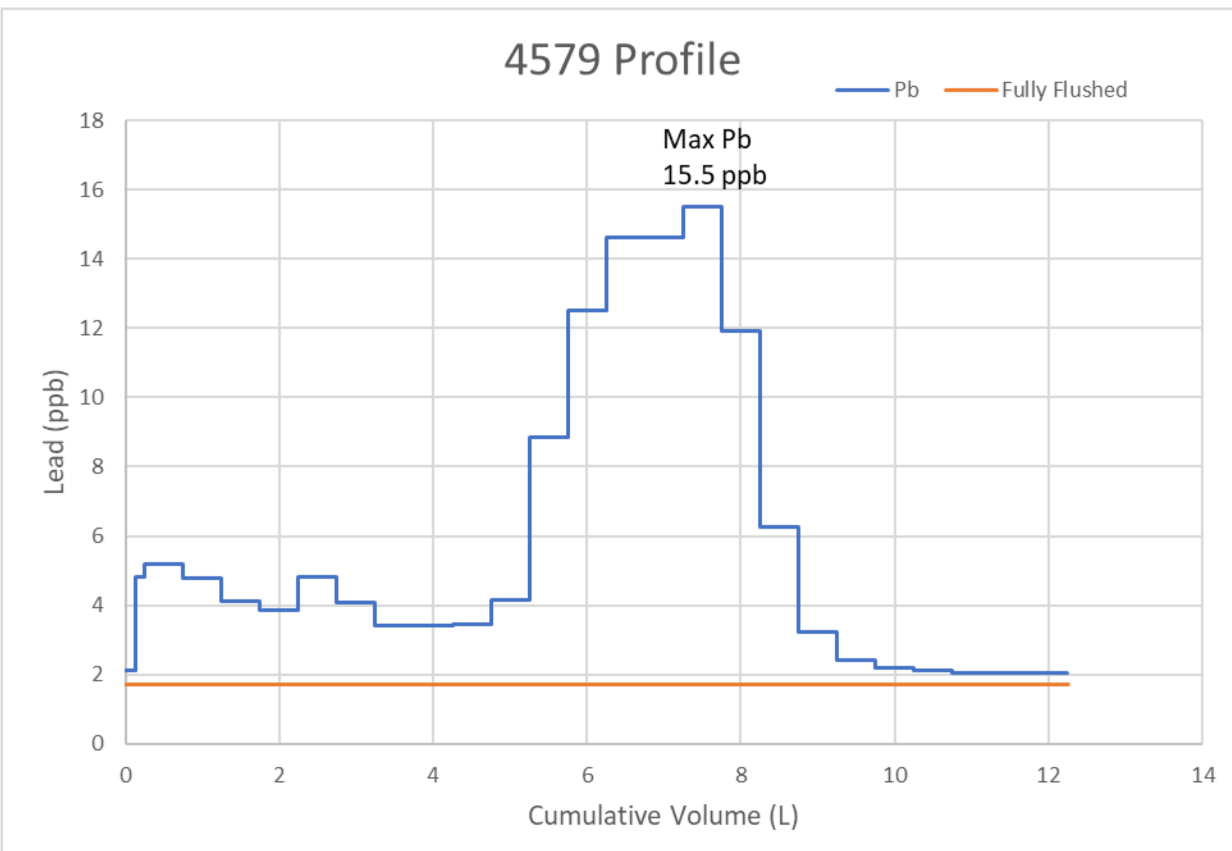
3492 Profile
Pb
Fully Flushed
Max Pb
4.2 ppb
Lead (ppb)
Cumulative Volume (L)



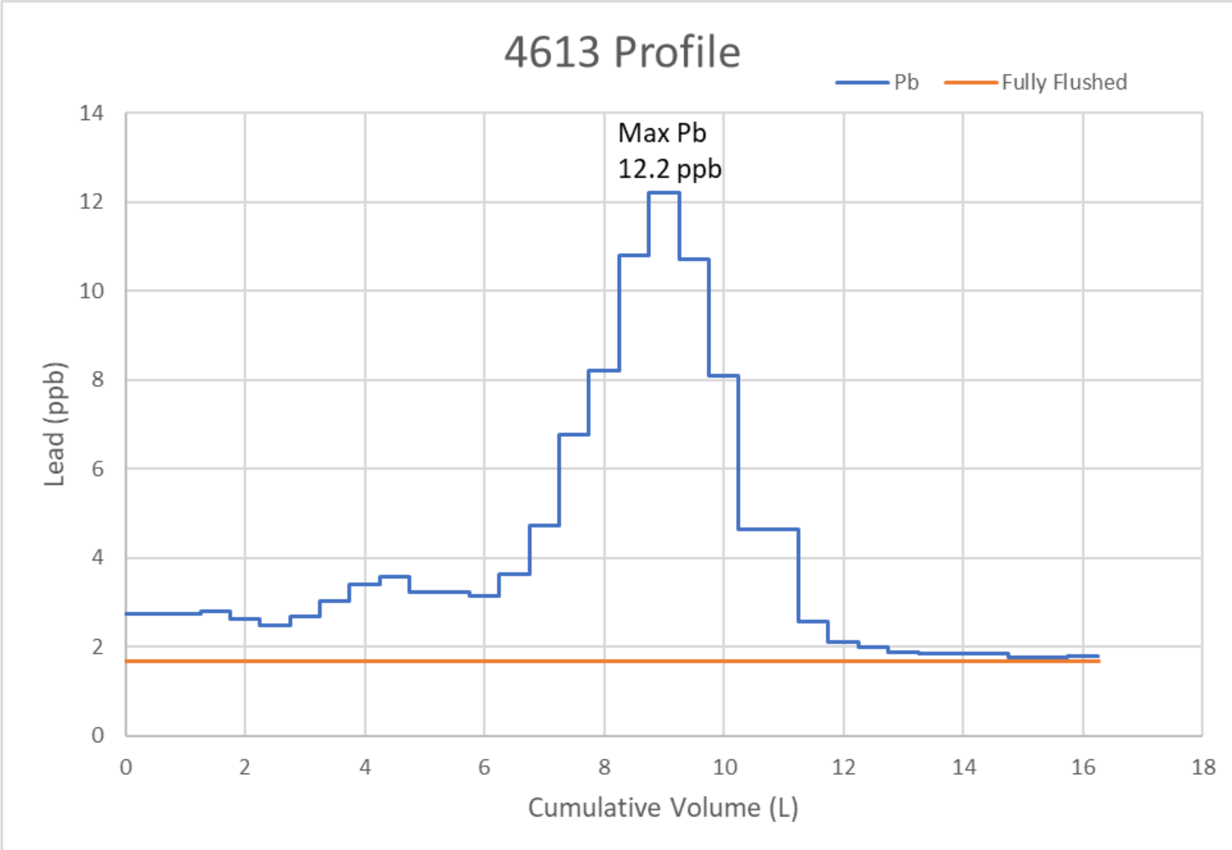
4348 Profile
Pb
Fully Flushed
Max Pb
8.61 ppb
Lead (ppb)
Cumulative Volume (L)

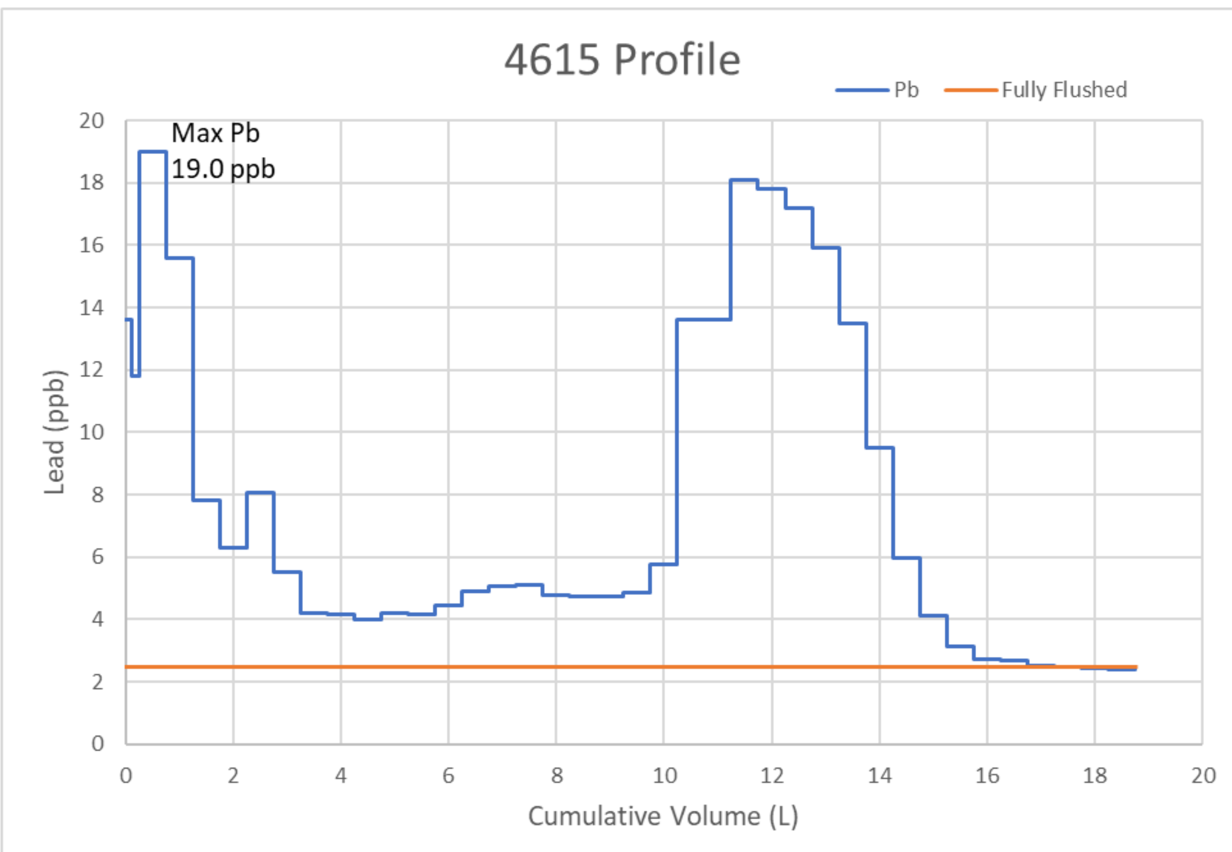


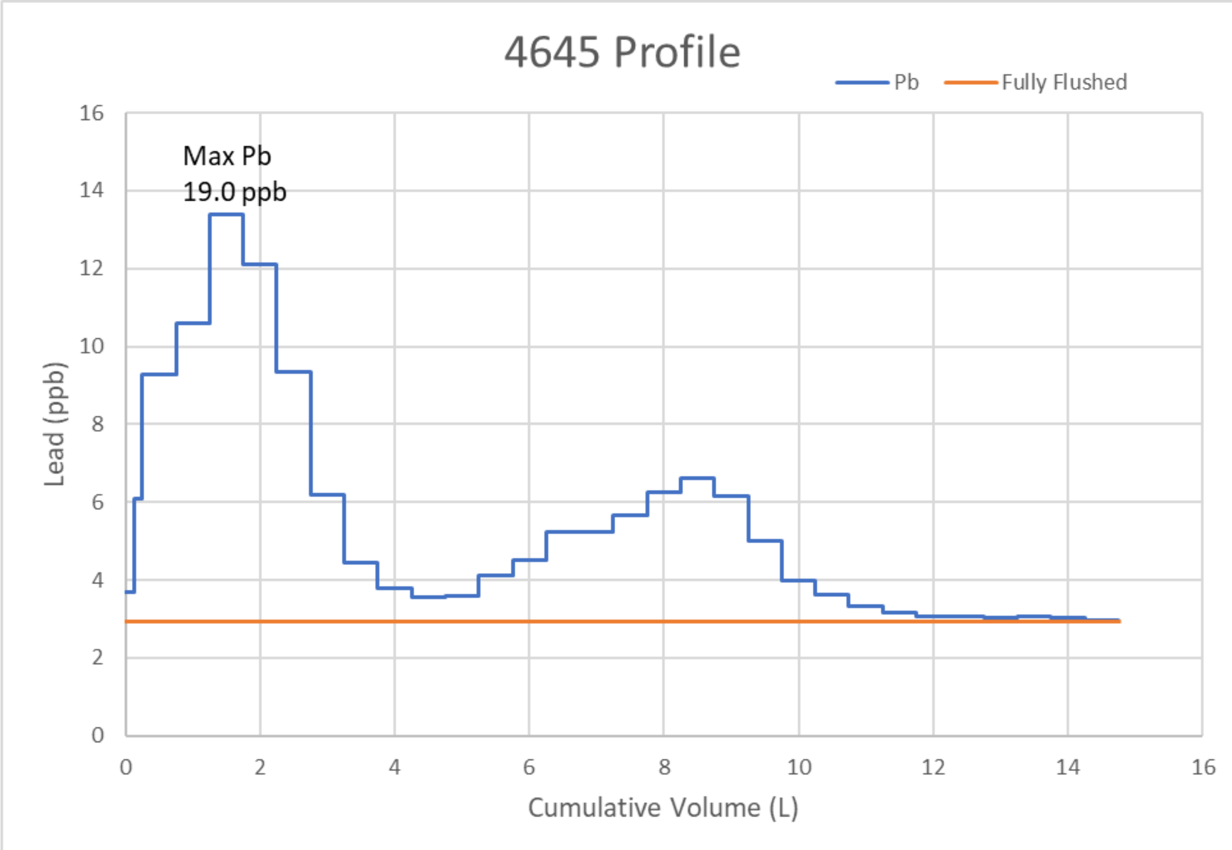
4518 Profile
Pb
Fully Flushed
Max Pb
3.98 ppb
Lead (ppb)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
16
18
Cumulative Volume (L)

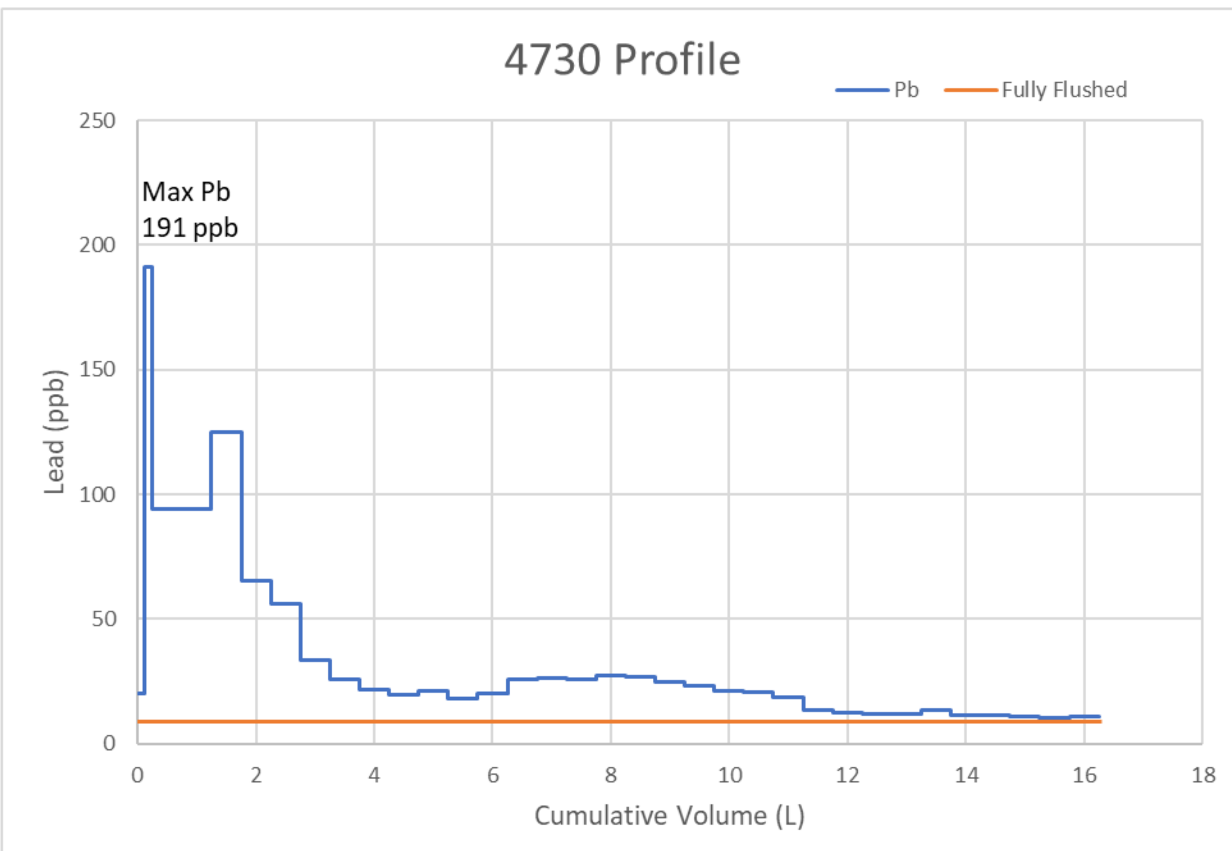


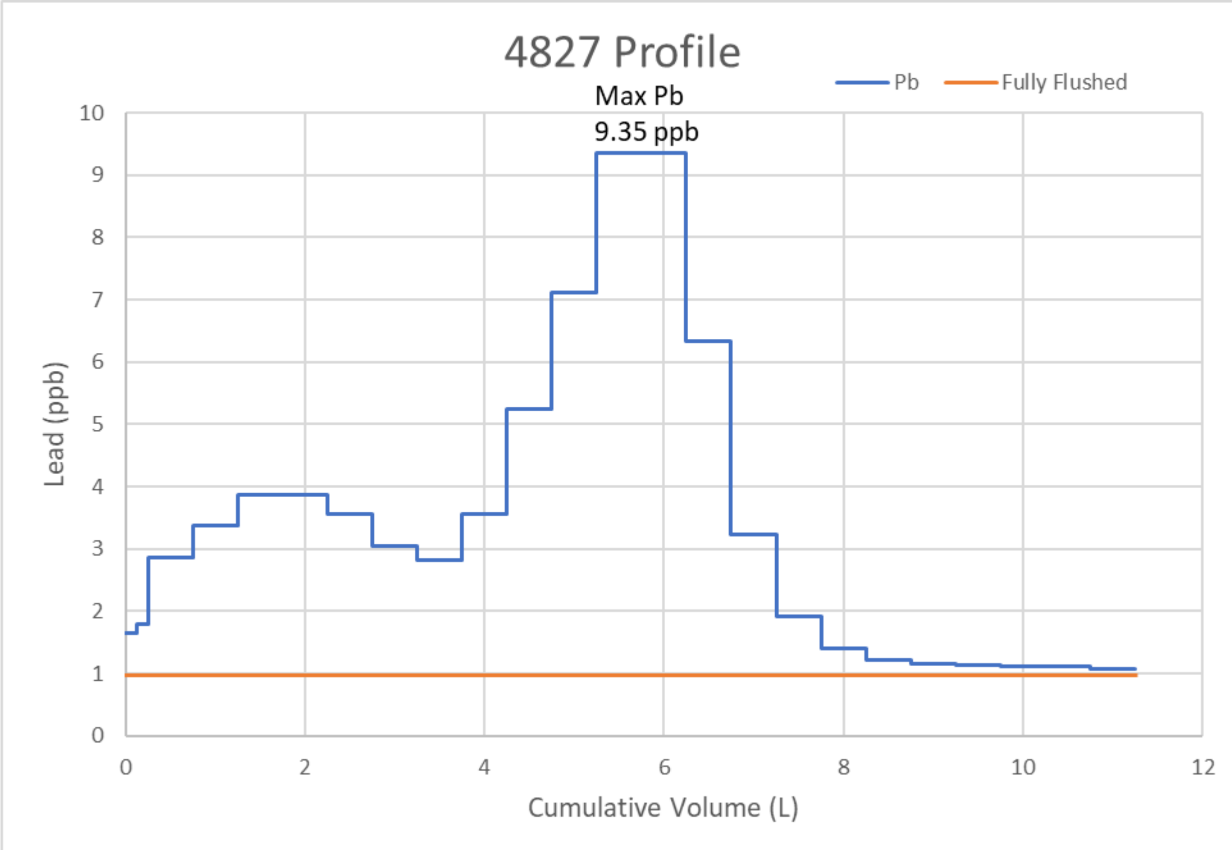
4579 Profile
Pb
Fully Flushed
Max Pb
15.5 ppb
Lead (ppb)
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
Cumulative Volume (L)


4613 Profile
Pb
Fully Flushed
Max Pb
12.2 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
14
16
18


4615 Profile
Pb
Fully Flushed
Max Pb
19.0 ppb
Lead (ppb)
Cumulative Volume (L)
0
2
4
6
8
10
12
14
16
18
20


4645 Profile
Pb
Fully Flushed
Max Pb
19.0 ppb
Lead (ppb)
0
2
4
6
8
10
12
14
16
Cumulative Volume (L)


4730 Profile
Pb
Fully Flushed
Max Pb
191 ppb
Lead (ppb)
0
50
100
150
200
250
0
2
4
6
8
10
12
14
16
18
Cumulative Volume (L)



Appendix C

BH_ChlorineResults.xlsx

Excel Sheet Containing Free and Total Chlorine Data

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