WANAQUE GRADIENT CORROSION CONTROL REVIEW

City of Newark
Lead and Copper Rule Compliance Study
Wanaque Gradient

Newark, NJ

City of Newark Department of Water and Sewer Utilities

June 28, 2019

CDM Smith

Table of Contents

List of Figures

List of Tables

CDM Smith

Appendices

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Section 1

Introduction and Background

The City of Newark (Newark) supplies approximately 80 million gallons per day (mgd) of water to a population of over 300,000 customers located in Newark, NJ and its surrounding communities. Newark's population of approximately 280,000 receives water through a large, complex distribution system that is managed by the City of Newark's Department of Water and Sewer Utilities (Department).

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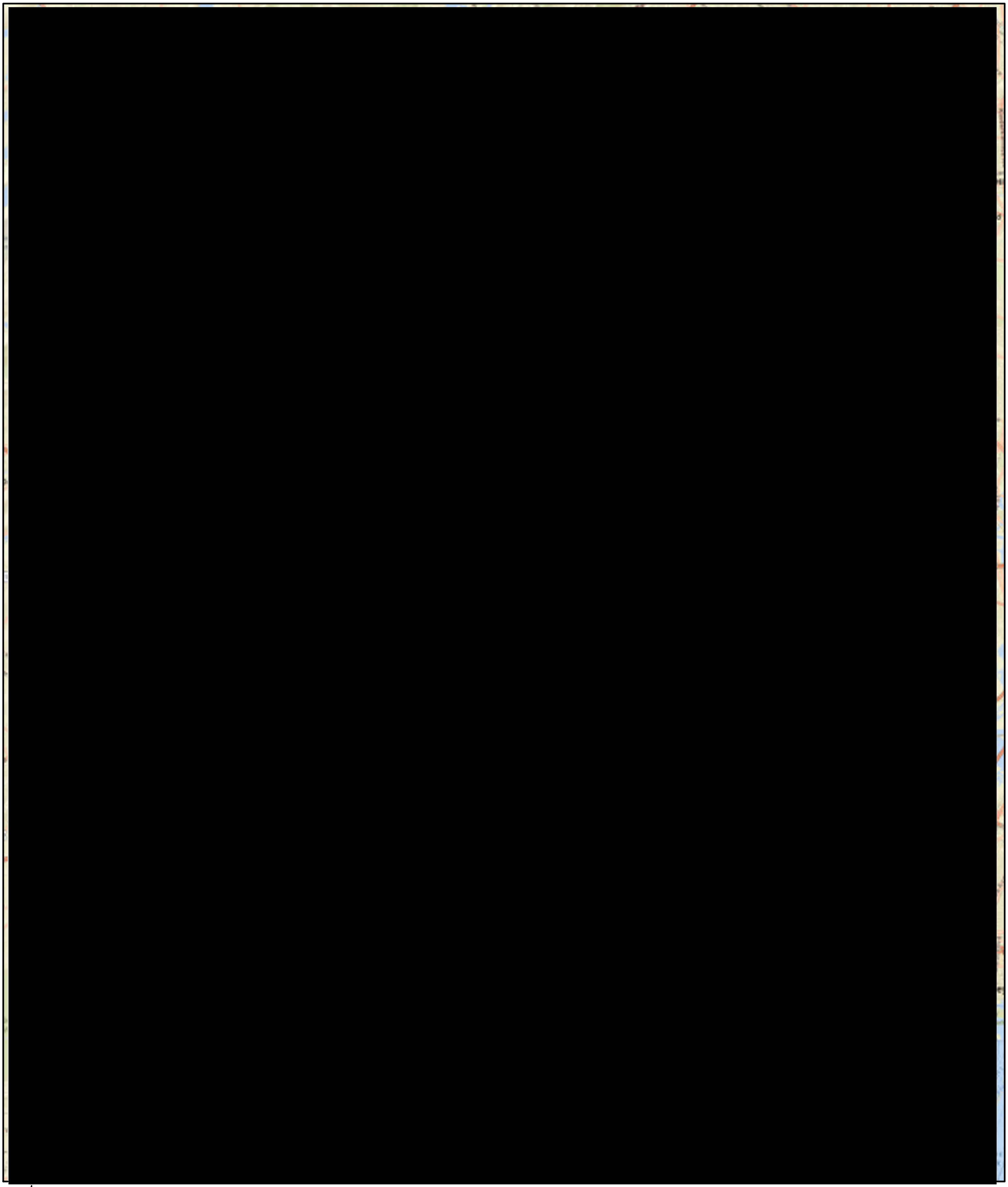
During the January to June 2017 Lead and Copper Rule (LCR) sampling round, Newark exceeded the Action Level (AL) for lead at the 90th percentile, based on sample results taken at 233 residences. On July 11, 2017, the New Jersey Department of Environmental Protection (NJDEP) sent a letter to Newark that outlined a series of required actions in response to the AL exceedance. Of the requirements, NJDEP required Newark to submit an Optimal Corrosion Control Treatment (OCCT) recommendation in accordance with 40 CFR 141.82(a) no later than six (6) months after the monitoring period when the AL was exceeded, or by December 31, 2017.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N

0 1.4 2.8 5.6 Miles

Newark Water System Overview

Figure 1-1

In response to NJDEP, Newark submitted an OCCT Memorandum on December 27, 2017. The 2017 OCCT Memorandum outlined the following recommended actions:

- Continue to collect the Water Quality Parameter data
- Completion of a corrosion control optimization desktop study
- Undertake a coupon study at several locations in the distribution system
- Conduct pipe loop testing

The 2017 OCCT Memorandum proposed the following Water Quality Parameters (WQPs) to be maintained for the Pequannock system:

- pH over 7.2
- Alkalinity over 30 mg/L
- Silica over 6.0 mg/L as SiO_2

Newark committed to increasing the sodium silicate dose to 12-15 mg/L from 8-12 mg/L, effective July 24, 2017.

The 2017 OCCT Memorandum also proposed the following WQPs to be maintained for the Wanaque Gradient in Newark's distribution system:

- pH over 7.2
- Alkalinity over 30 mg/L
- Orthophosphate above 0.4 mg/L as PO_4-P (or 1.2 mg/L as PO_4)

Optimal WQPs are typically established once corrosion control is optimized and after two consecutive 6-month follow-up WQP monitoring is performed showing compliance with the LCR. Since the 2017 OCCT Memorandum was issued, Newark has exceeded the lead AL in the second half of 2017 and both the first and second half of 2018. Therefore, Optimal WQPs have not yet been set by NJDEP.

In October 2018, the draft "Pequannock WTP Corrosion Control Review and Recommendations" prepared by CDM Smith provided the results of an evaluation of Newark's current corrosion control including an analysis of historic water quality and lead levels. The study indicated that an increase in lead levels since 2015 was occurring in the service area supplied by the Pequannock Gradient and not in the service area supplied by the Wanaque Gradient. Once this was determined, further analysis conducted for the October 2018 draft report focused on the Pequannock Gradient, including sequential sampling at customer homes and pipe scale analyses, to diagnose the cause of the increased lead levels.

Ultimately, it was concluded that the corrosion control treatment in the Pequannock system using sodium silicate was no longer effective for Newark's current water quality. As a result, protective scales, that had previously formed on lead service lines, were no longer providing corrosion protection. It was also determined that flushing at the tap, a method generally accepted as a way for homeowners with lead service lines or lead-containing plumbing components to reduce exposure to lead in drinking water, was less effective for this particular situation. Furthermore, since the scale was unstable and could be easily disturbed, there was potential for releasing particulate lead into the water during flushing.

Since the Pequannock report was issued in October 2018, Newark constructed a zinc orthophosphate feed system at the Valley Road Rechlorination Station and commenced dosing orthophosphate on May 7, 2019. This system will benefit all residents served by Newark within the Pequannock Gradient. Zinc orthophosphate forms a protective barrier to reduce lead from leaching into the drinking water. In the interim while the zinc orthophosphate scale develops, Newark has established a program to distribute water filters and replacement cartridges to single family or multi-family homes in the Pequannock Gradient that have a lead service line or have interior plumbing comprised of copper piping with lead solder. Newark anticipates continued exceedances of the lead AL until the zinc orthophosphate can take effect, therefore, the filter distribution will continue until test results show lead levels decreasing in the system. In addition, Newark has increased its public education and awareness to notify residents of the lead levels found in older homes, particularly targeting those in higher risk categories.

On October 26, 2018, NJDEP provided comments on the October 2018 Pequannock draft report including requiring a more detailed corrosion control evaluation for the Wanaque Gradient, including sequential sampling, pipe scale analysis, and determining whether or not "elevated lead levels in the Wanaque Gradient can be attributed to the influence of Pequannock Gradient water leaking through division gates." This report is a response to the first comment in NJDEP's October 26, 2018 letter and focuses on the Wanaque water supply system to review the current corrosion control treatment and, if necessary, provide any recommendations for improvements.

A draft of this report was provided on February 2, 2019, while some of the testing and investigations were still ongoing. This June 2019 draft report includes updated information on the Wanaque system.

1.1 Current Corrosion Control Treatment (CCT)

The Wanaque water supply system, operated by the NJDWSC, has dosed zinc orthophosphate in Totowa, upstream of their Belleville Reservoir Complex, since the mid-1990s. When the LCR was established in 1991, both the Pequannock and Wanaque Gradients showed evidence of high lead levels when performing the initial requisite monitoring programs in 1992 and 1993. At that time, both systems commenced corrosion control studies and implemented corrosion control treatment (CCT) in the mid- to late-1990s.

NJDWSC typically targets the following water quality at the Belleville Reservoir Complex: pH of approximately 7.8 to 8.0, orthophosphate residual of approximately 1.8 to 2.2 mg/L as PO_4, and a free chlorine residual of 0.80 to 1.0 mg/L. NJDWSC supplies several communities with drinking water either on a regular or emergency basis, including Wayne, Cedar Grove, Bayonne, Kearny, Montclair, Ringwood, communities served by Passaic Valley Water Commission (PVWC), and Newark. Some of these communities are supplied with water upstream of the zinc orthophosphate addition in Totowa, and add their own corrosion inhibitor, and some are supplied with water downstream of the zinc orthophosphate addition. Of all the water suppliers that are provided water by NJDWSC, only PVWC and Newark have experienced non-compliance with the LCR within the last 10 years. Both PVWC and Newark have other sources of water with separate treatment in addition to the water obtained through NJDWSC.

Water quality within the Wanaque gradient of the Newark distribution system supplied by NJDWSC is discussed in Section 3.

1.2 Lead and Copper Rule Compliance Sampling Results

As noted above, due to consecutive rounds of lead AL exceedances in 1992 (90th percentile above the AL of 15 µg/L), both the Pequannock and Wanaque systems implemented CCT in the 1990s. After 1992, LCR compliance sampling was performed in 1998, 2002, 2003, 2006, 2009, 2012, 2015, 2017 and 2018 at residences throughout the City.

Maps showing the locations and lead concentration ranges for all compliance sampling events, including the initial sampling in 1992 leading to implementation of CCT, are provided in **Figures 1-2** through **1-13**. As shown in the figures, Newark experienced a period with very low lead concentrations at compliance sampling pool locations between 1998 and 2012. During this period, the compliance sampling locations varied by year and were not consistently representative of both the Pequannock and Wanaque supplies. For example, in 2002 and 2009, only homes receiving Wanaque water were sampled. In 1998 and 2006, only homes receiving Pequannock water were sampled. In 2015, slightly elevated lead concentrations were found, but they were still below the AL. Due to the significant increase in customer requested samples in 2018 (a total of 448 tested samples), the January to June 2018 and July to December 2018 graphs, **Figure 1-12** and **Figure 1-13** respectively, show both the results from the LCR compliance samples with verified pipe materials and the results from the customer requested samples that have not been verified and are not included in the 90th percentile calculation for LCR compliance. The LCR samples are identified as circles while the customer requested samples are identified as squares. Approximately 30 of the customer-requested samples were listed under a different address than their account address. The locations are still being determined and will be added to the map for the final report.

Lead levels exceeded the AL during the first and second half of 2017, as well as the first and second half of 2018. The AL was also exceeded in the last three sampling rounds in Bloomfield, one of Newark's consecutive systems, which receives a large percentage of its supply from Newark's Pequannock WTP. As corrosion control chemistry transitions are a slow process, it cannot be determined exactly when the lead levels started to increase. To monitor the transition of lead levels, the acceptable practice is to maintain routine monitoring of the water quality parameters as well as continue tap sampling under the LCR. Newark is in compliance with the LCR by performing all required monitoring and actions triggered by a lead AL exceedance.

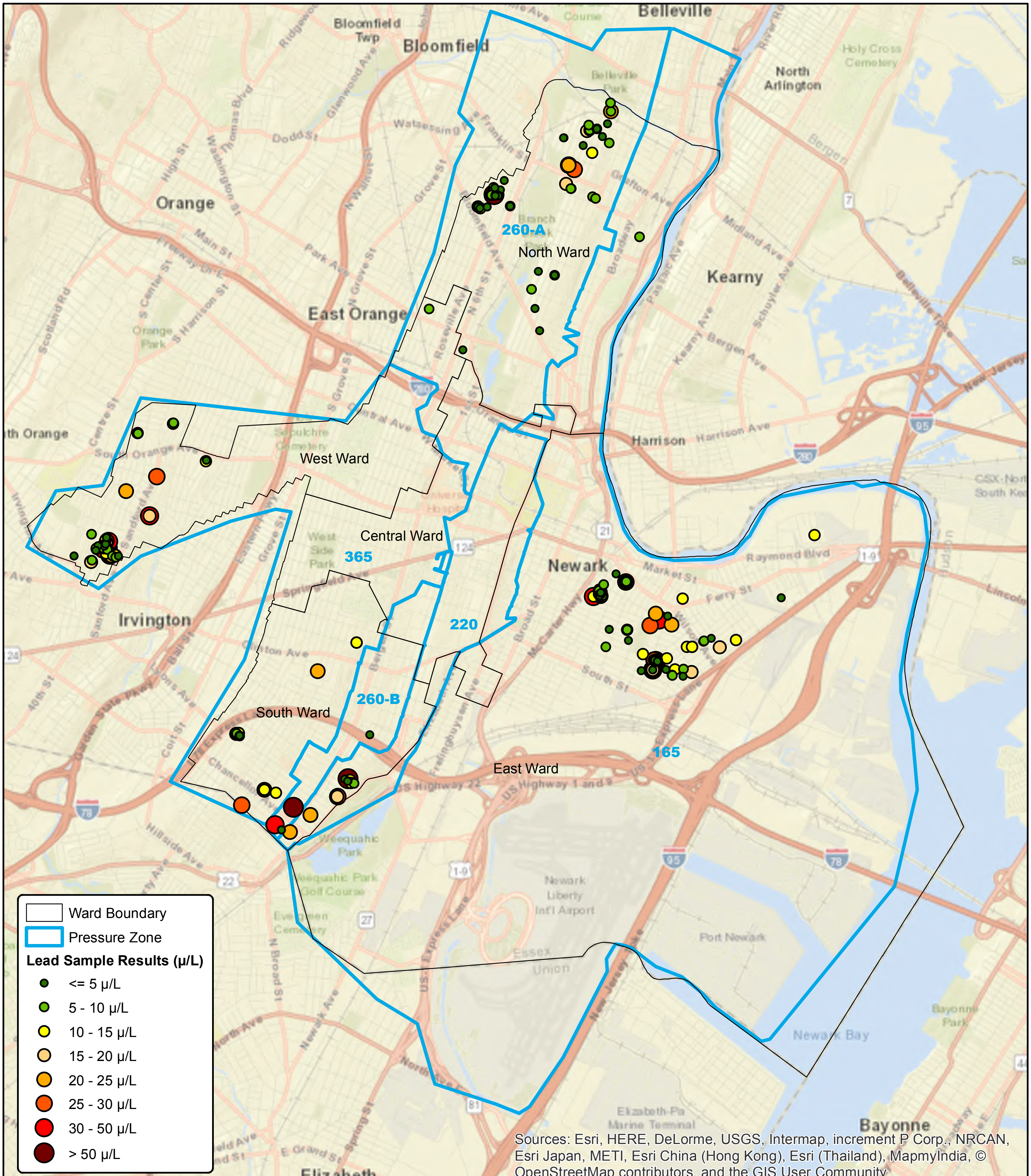
The LCR AL for copper is 1.3 mg/L at the 90th percentile value. Newark has not experienced high copper levels in their system based on the data analyzed other than one sample in the sequential sampling discussed in Section 4. Optimization of treatment for copper, therefore, is not addressed in this report.

1.3 Wanaque WQP and Test Locations

Water Quality Parameters (WQPs) are monitored at sample locations throughout a distribution system and are used to regularly monitor conditions pertaining to corrosion control. The sample locations and WQPs are typically established by the water utility and approved by NJDEP. Optimal targets are set once a utility is in compliance with the LCR. Newark proposed target WQPs as stated earlier in this Section and has been monitoring their WQPs since July 2016 on a bi-weekly basis. The monitoring locations for Newark's current WQPs are shown in **Figure 1-14**. According to the list, there are 13 WQP sampling sites in the Pequannock service area (labeled with "P") and 12 WQP sampling sites in the Wanaque service area (labeled with "W"). However, based on a recent review of the WQP locations, some updates have been proposed and are in the process of being finalized with the NJDEP. Based on the review, it appears that the following WQP sampling sites will need to be updated:

- 2W – Labeled as Wanaque but appears to be located in the Pequannock service area
- 8W – Labeled as Wanaque but appears to be located in the Pequannock service area
- 11W – Labeled as Wanaque but appears to be located in the Pequannock service area
- 10P – Labeled as Pequannock but appears to be located in the Wanaque service area

Therefore, these WQPs were evaluated based on the updated water sources for the water quality evaluations presented in Section 3.



Lead Level in the City of Newark

N

0 0.5 1 2

Miles

Data Collected: 1992

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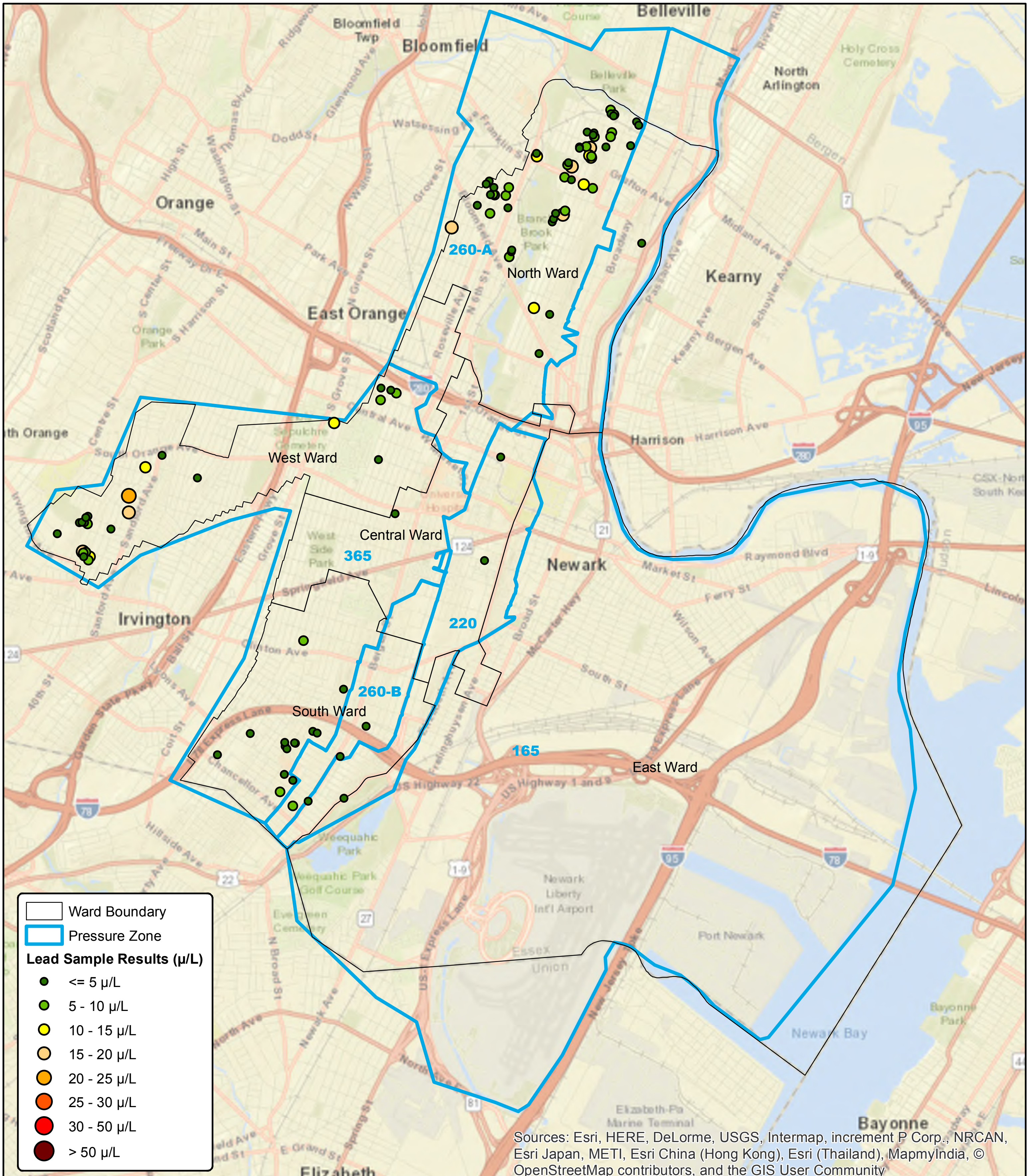
Figure 1-2

Angellja G:\225083_\02_MXD\LeadSamples1992.mxd 2/7/2018



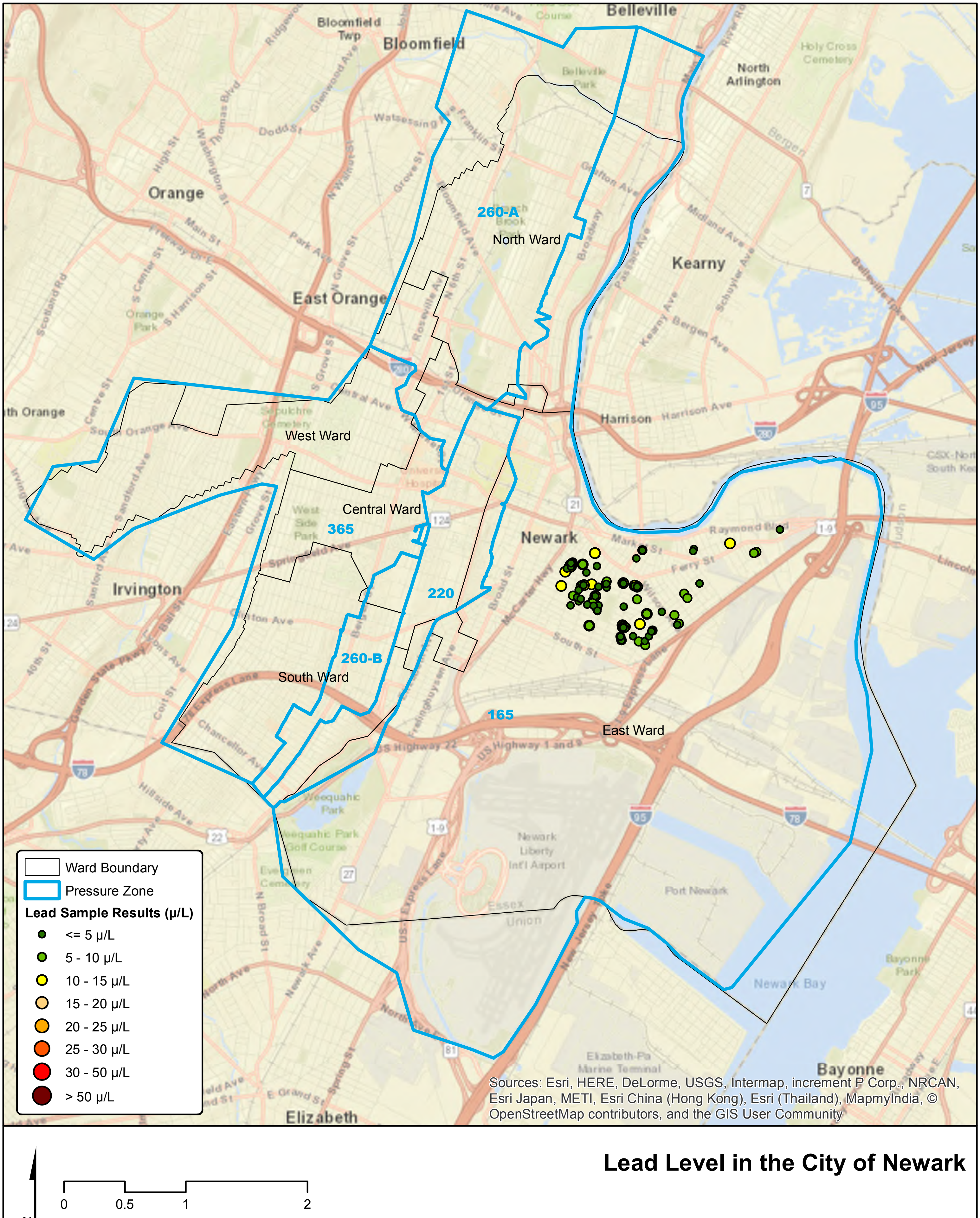
Lead Level in the City of Newark

Data Collected: 1998

CDM Smith

Figure 1-3

Angellja G:\225083_\02_MXD\LeadSamples1998.mxd 2/7/2018



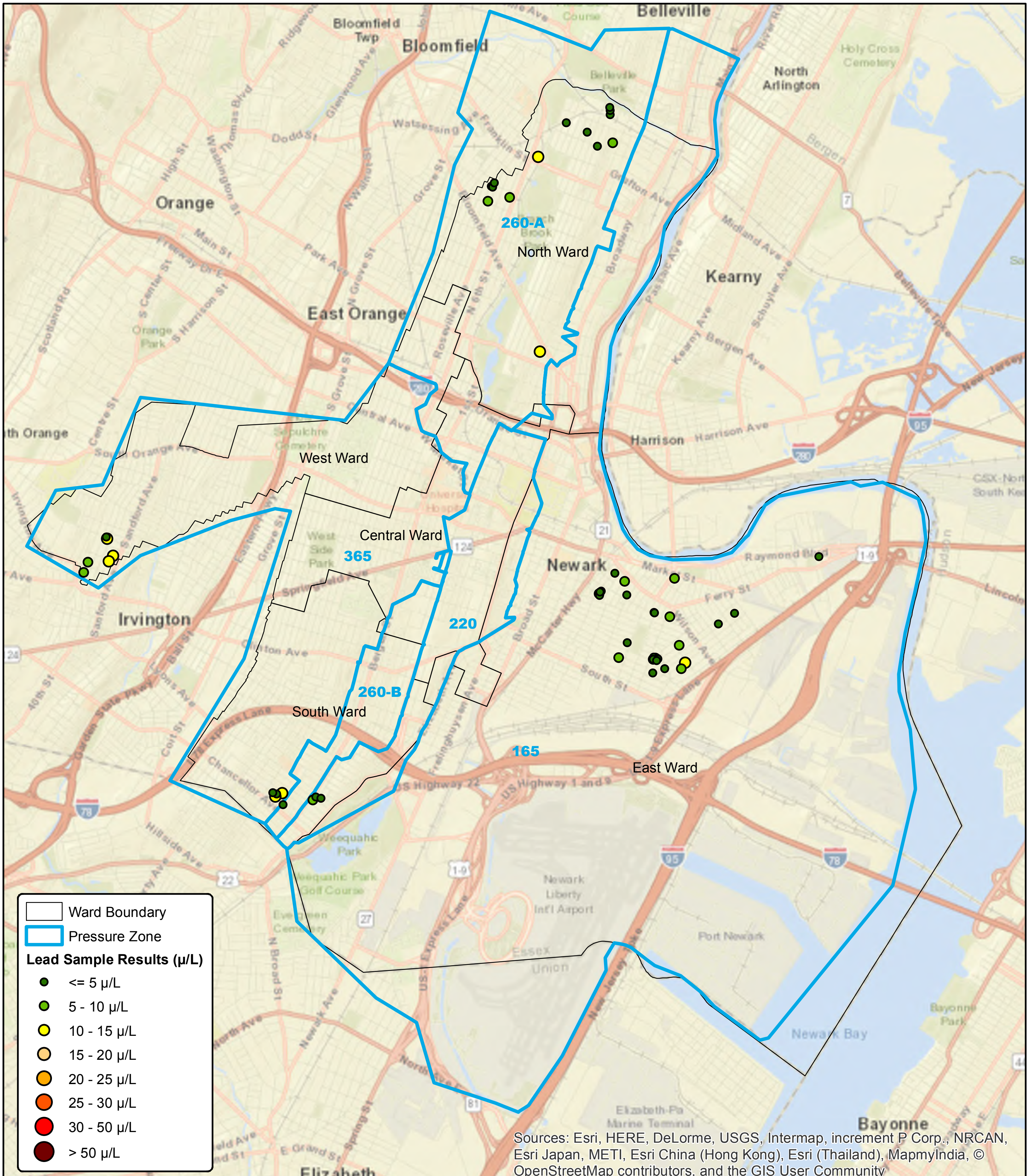
Lead Level in the City of Newark

Data Collected: 2002

CDM Smith

Figure 1-4

Angellja G:\225083_\02_MXD\LeadSamples2002.mxd 2/7/2018



N

0 0.5 1 2

Miles

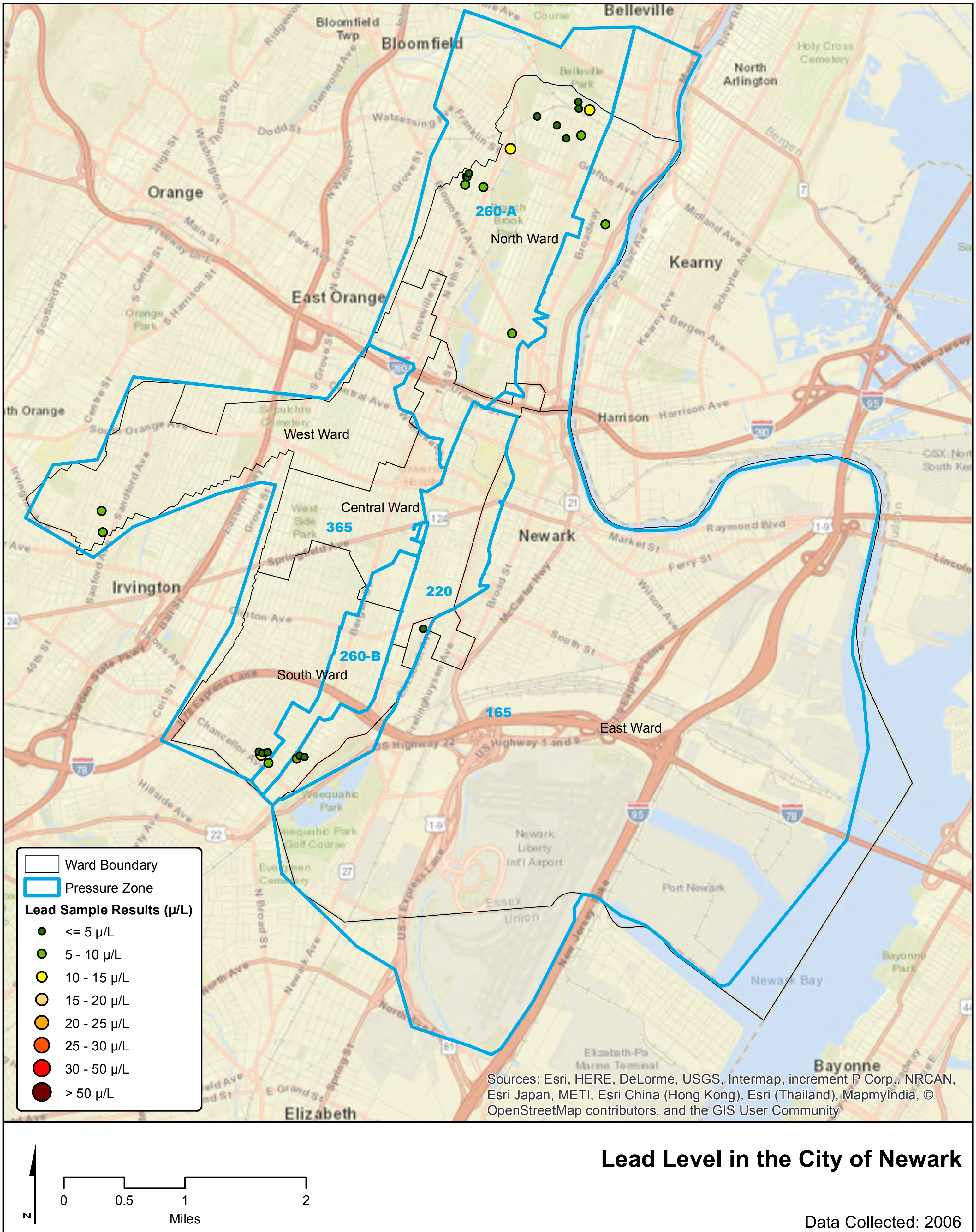
Lead Level in the City of Newark

Data Collected: 2003

CDM Smith

Figure 1-5

Angellja G:\225083_\02_MXD\LeadSamples2003.mxd 2/7/2018



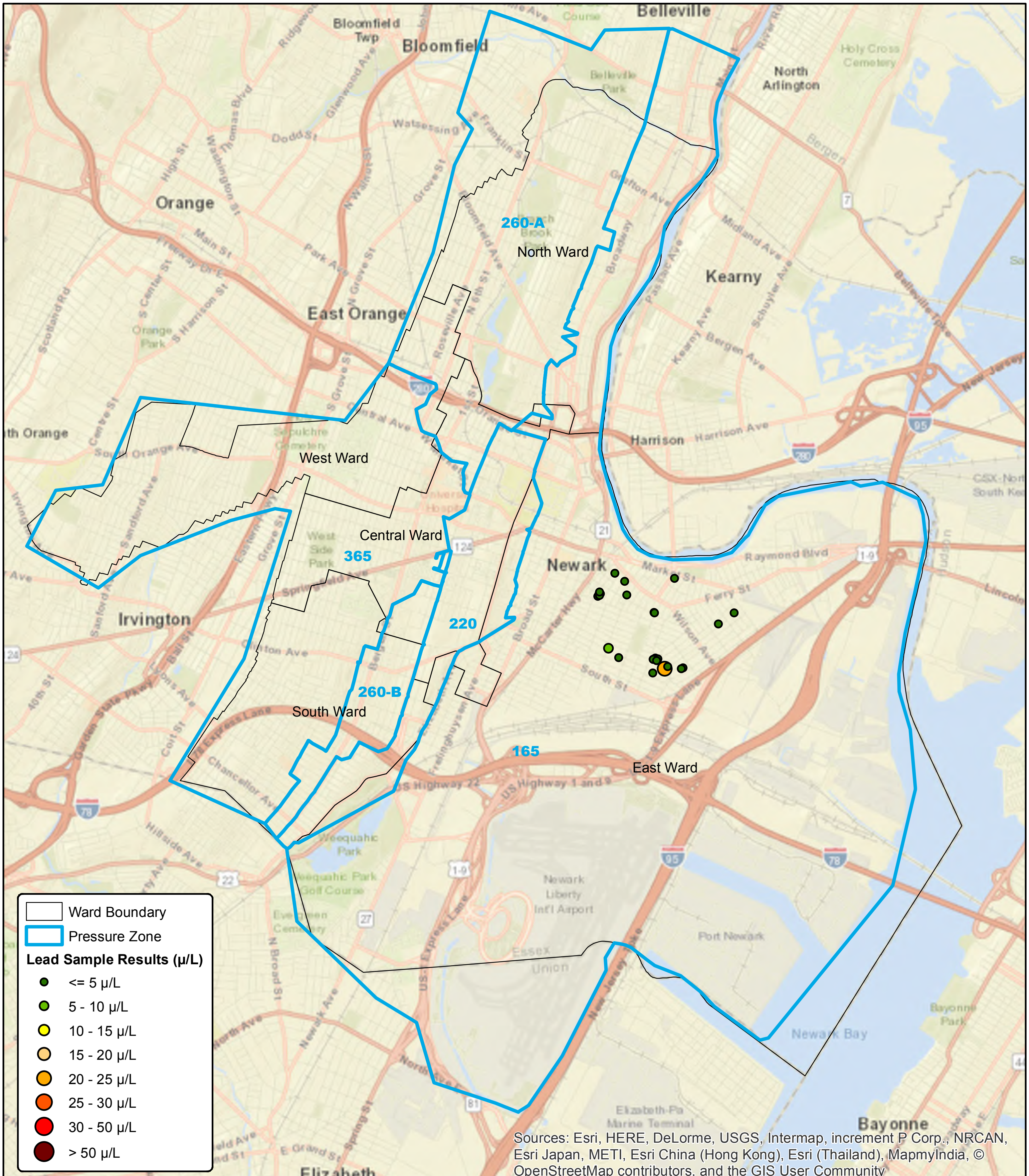
Lead Level in the City of Newark

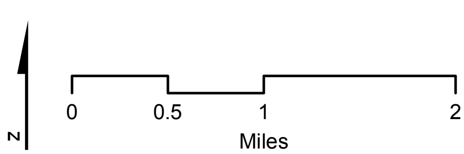
Data Collected: 2006

CDM Smith

Figure 1-6

Angellja G:\225083_\02_MXD\LeadSamples2006.mxd 2/7/2018



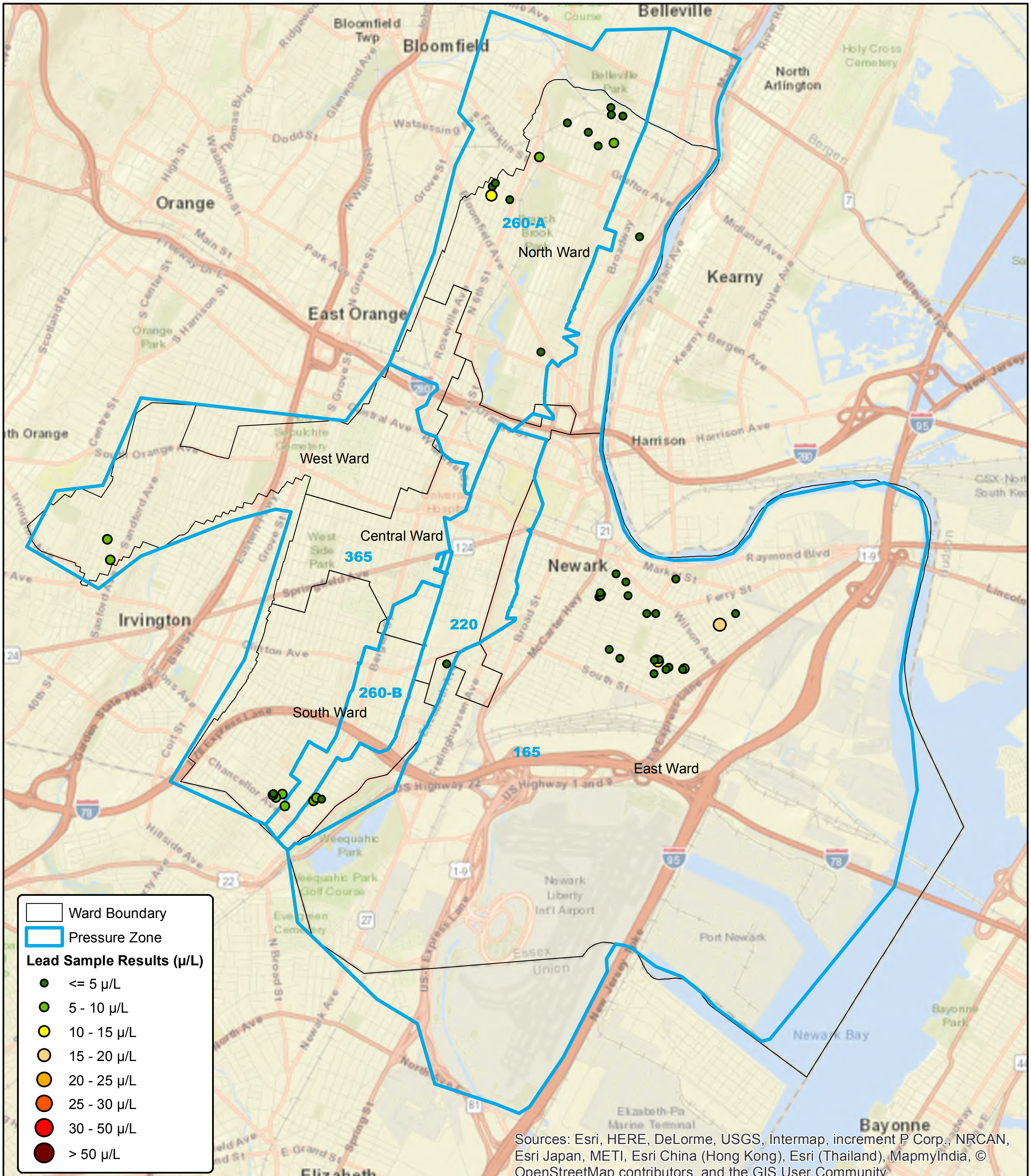


Lead Level in the City of Newark

Data Collected: 2009

Figure 1-7

Angellja G:\225083_\02_MXD\LeadSamples2009.mxd 2/7/2018



N

0 0.5 1 2
Miles

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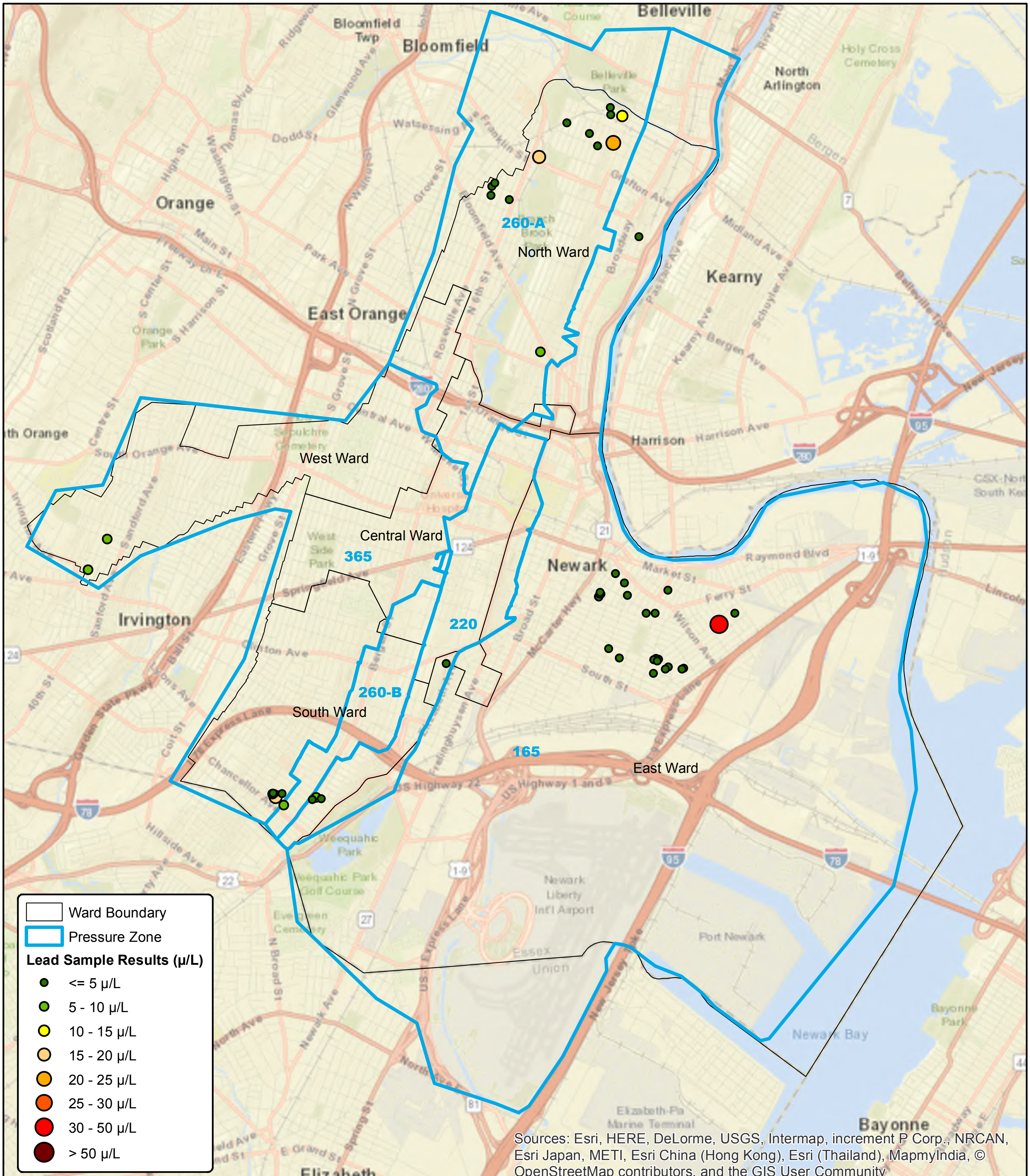
Lead Level in the City of Newark

Data Collected: 2012

Figure 1-8

Angellja G:\225083_\02_MXD\LeadSamples2012.mxd 2/7/2018



N

0 0.5 1 2
Miles

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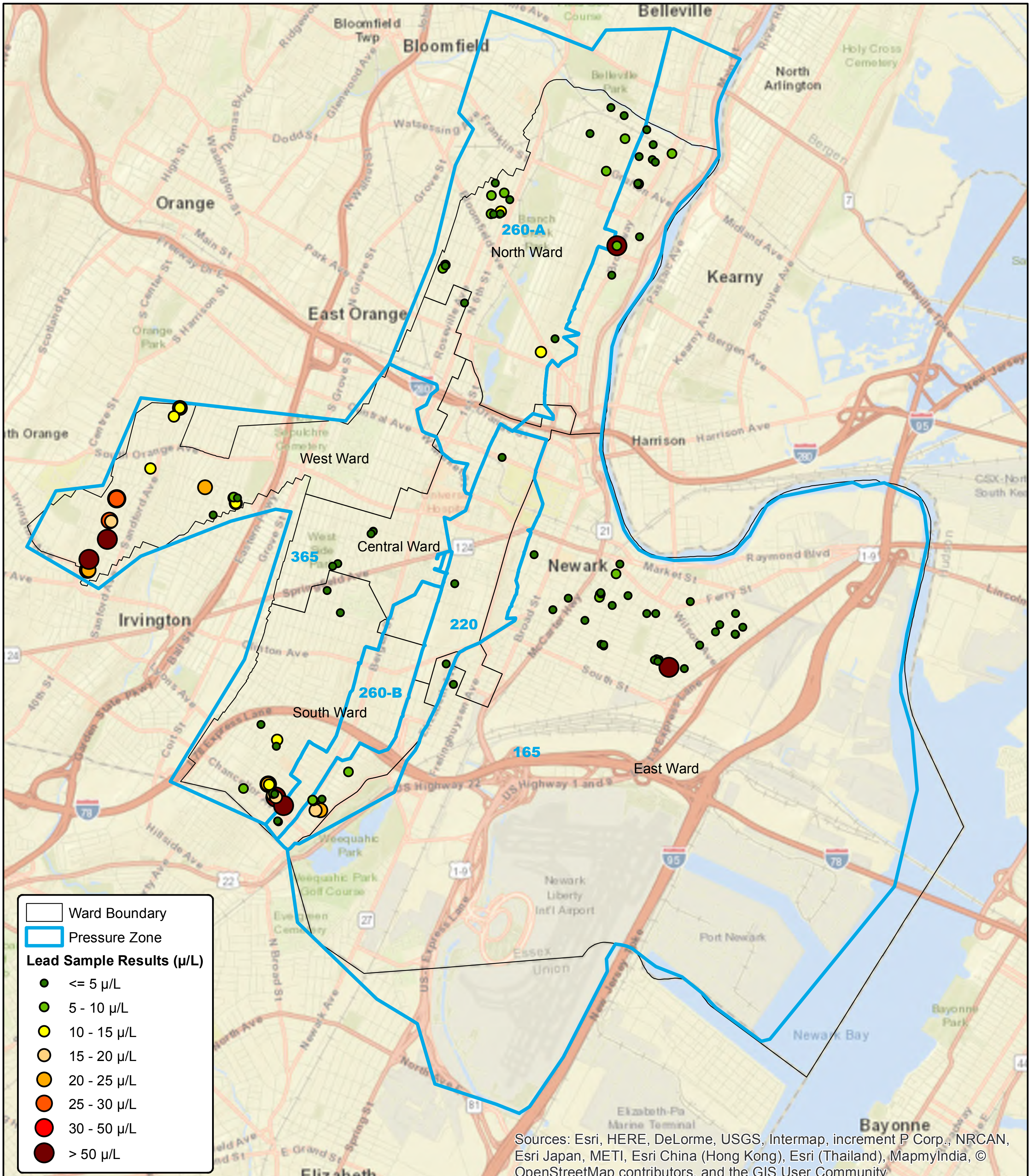
Lead Level in the City of Newark

Data Collected: 2015

Figure 1-9

Angellja G:\225083_\02_MXD\LeadSamples2015.mxd 2/7/2018



N

0 0.5 1 2
Miles

Lead Level in the City of Newark

Data Collected: January - June 2017

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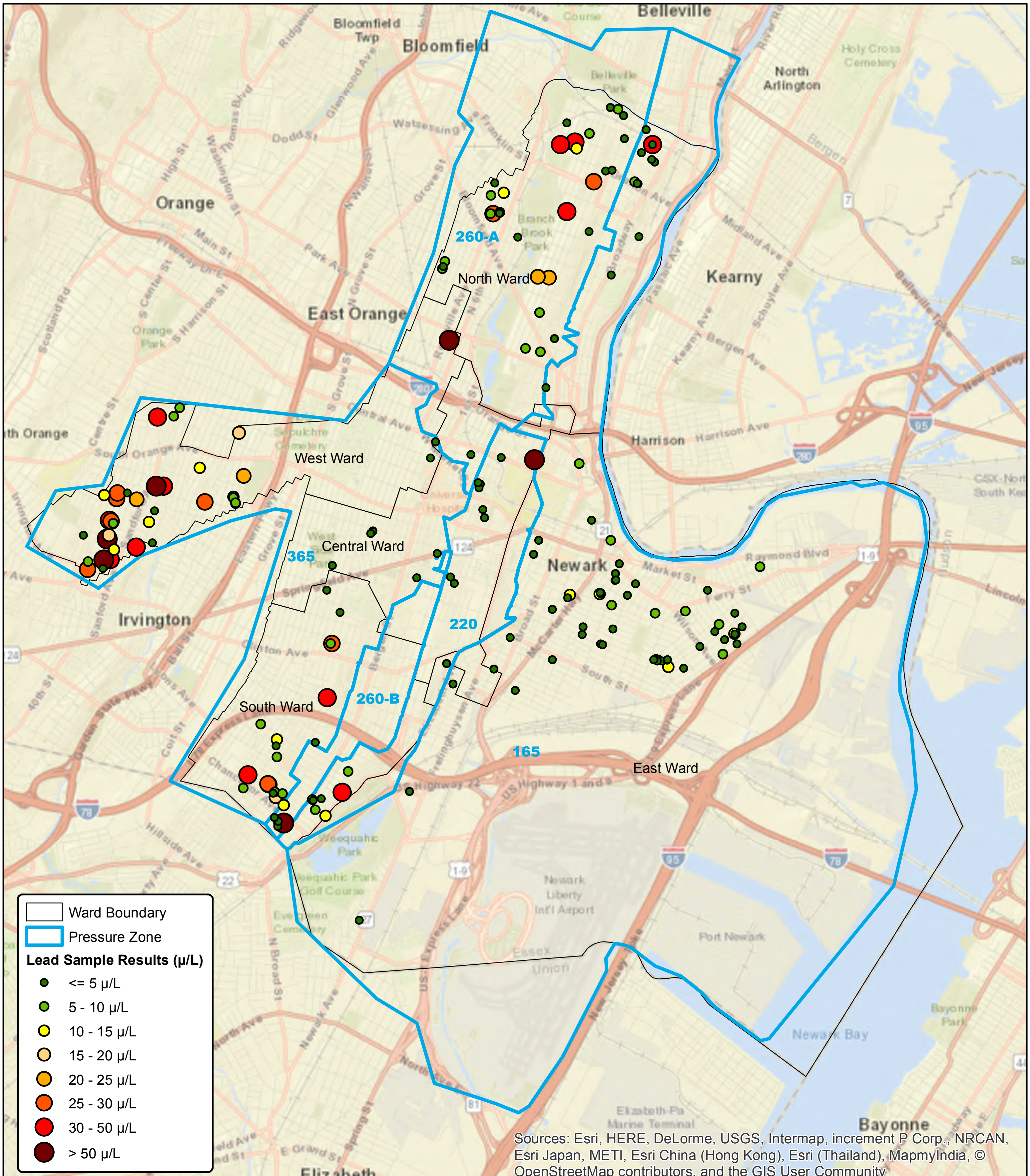
Figure 1-10

Angellja G:\225083_\02_MXD\LeadSamples2017_1-6.mxd 2/7/2018



N

0 0.5 1 2
Miles

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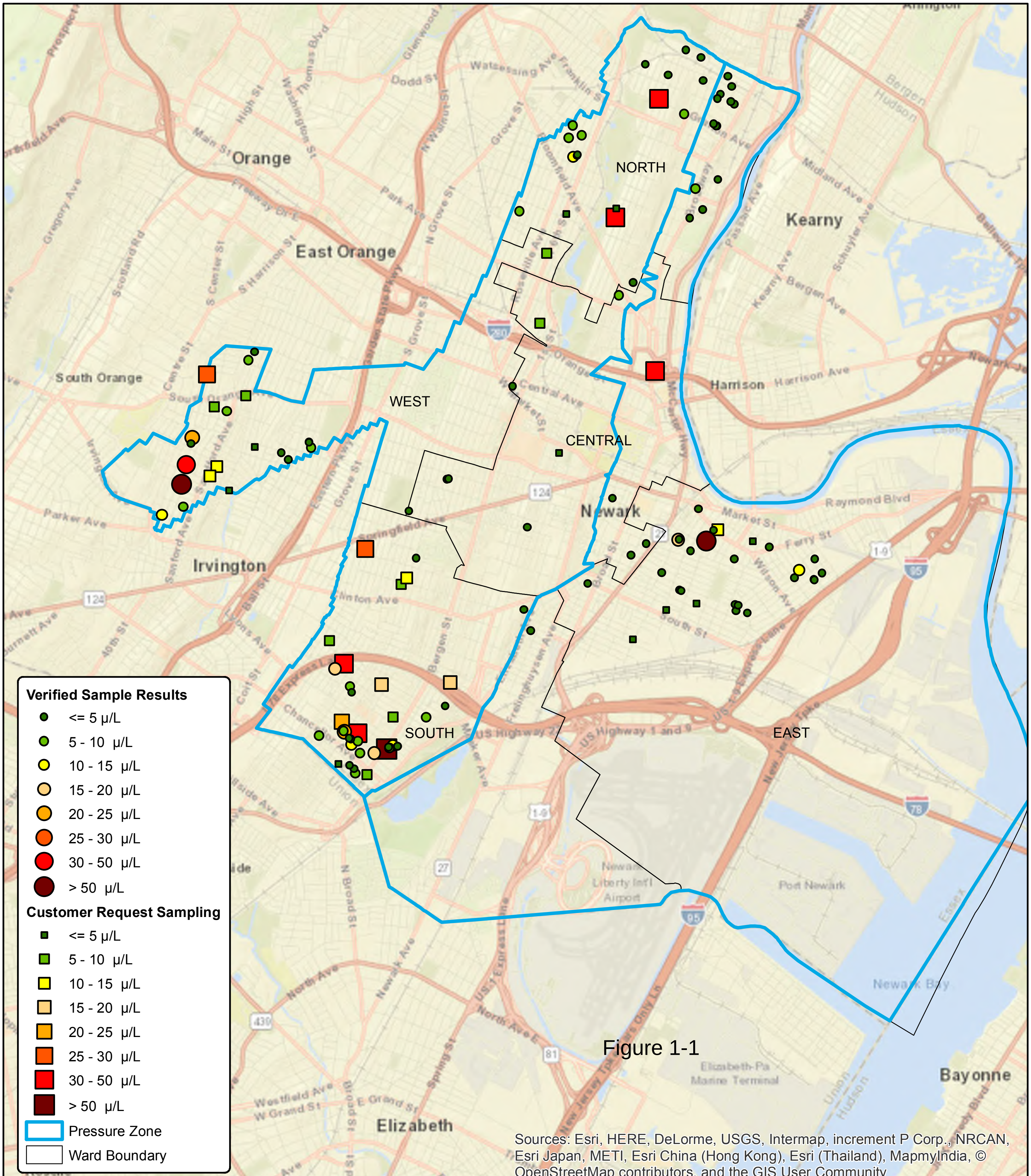
Lead Level in the City of Newark

Data Collected: July - December 2017

Figure 1-11

Angellja G:\225083_\02_MXD\LeadSamples2017_7-12.mxd 2/7/2018



N

0 0.5 1 2
Miles

CDM Smith

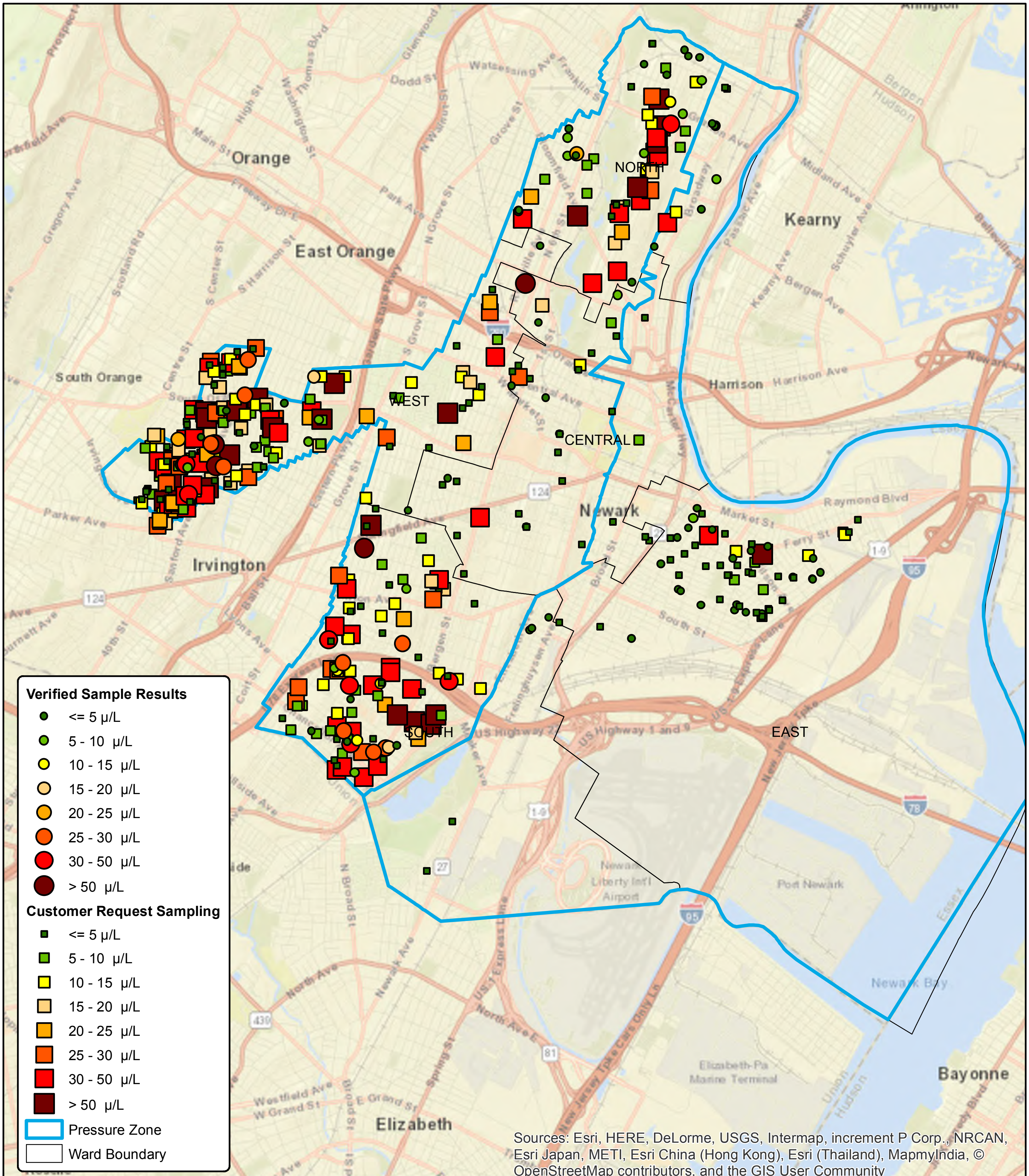
Lead Level in the City of Newark

LCR Sampling Pool and Customer Requested Samples

Data Collected: January through June 2018

Figure 1-12

angellja G:\NewarkLeadServiceLine\02_MXD\SamplingResultsMaps\2018Results\LeadSamplesJanToJune2018wCR.mxd 1/28/2019



N

0 0.5 1 2

Miles

CDM Smith

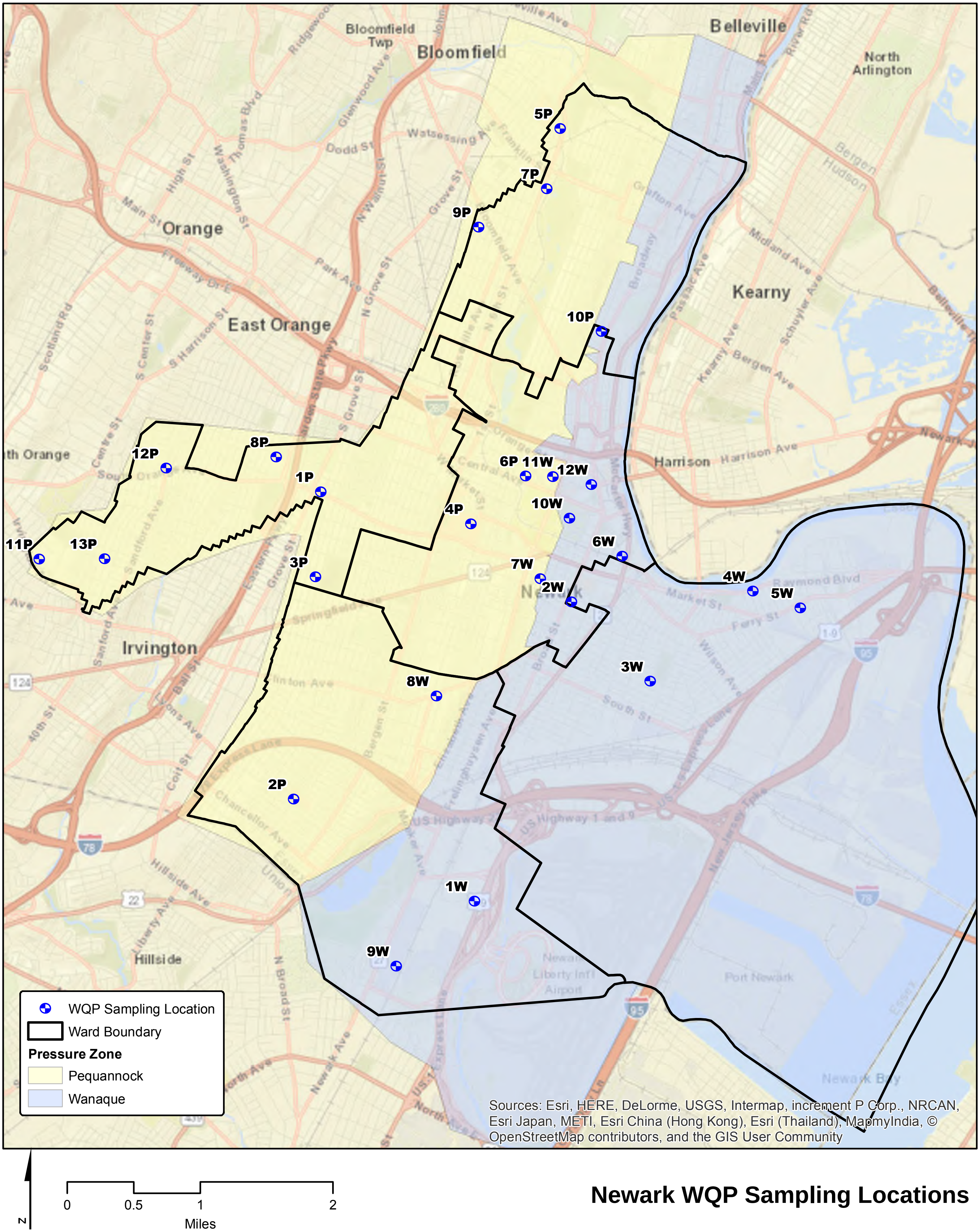
Lead Level in the City of Newark

LCR Sampling Pool and Customer Requested Samples

Data Collected: July through December 2018

Figure 1-13

angellja E:\NewarkLeadServiceLine\02_MXD\SamplingResultsMaps\2018Results\LeadSamplesJulyToDec2018wCR.mxd 1/28/2019



Newark WQP Sampling Locations

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Figure 1-14

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Section 2

Lead Frequency Distribution

A frequency distribution analysis was conducted using multiple rounds of compliance sampling data for both the Pequannock and Wanaque service areas. The analysis was conducted for each service area separately as the service areas receive different CCT as described in Section 1. Although regulatory compliance is based on the City of Newark as a whole, the corrosion control chemistry of the two service areas differ. Therefore, the systems were evaluated separately to understand the cause of the high lead levels found in homes within the City of Newark with lead service lines and/or plumbing components containing lead.

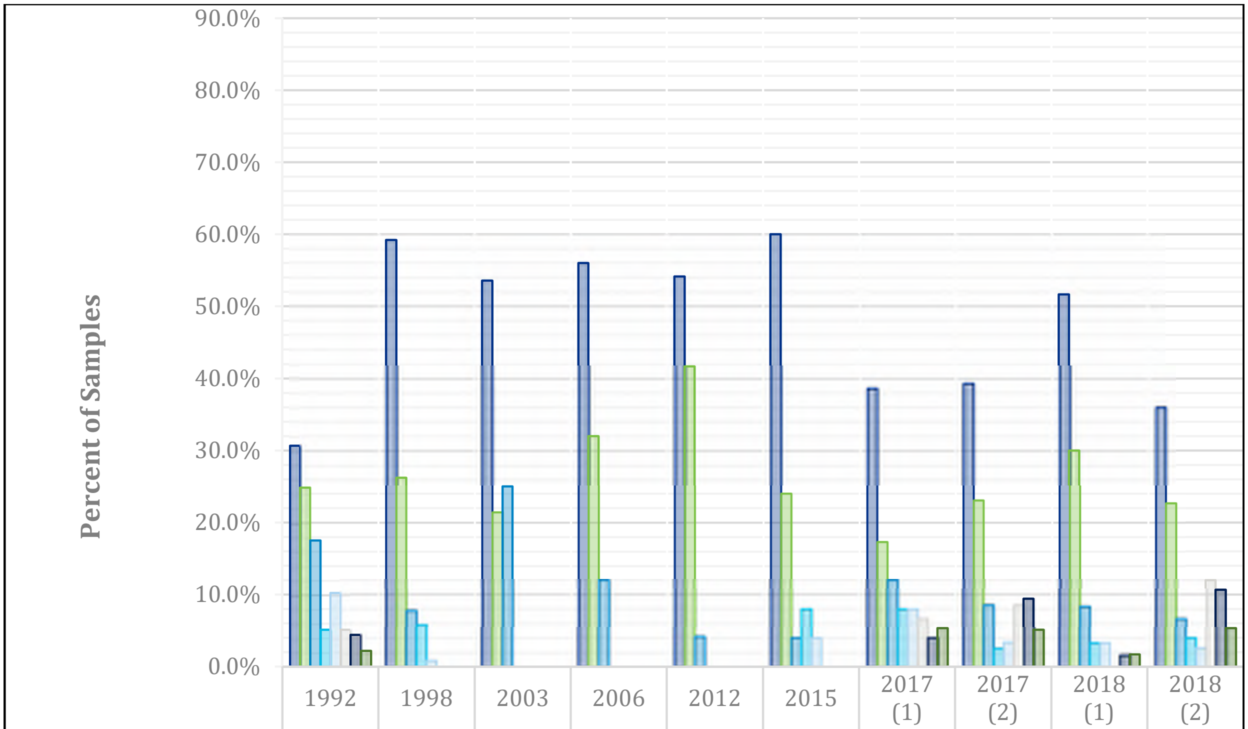
Frequency distributions can provide insight as to whether changes in lead levels may be the result of CCT, sampling variability, or a combination of the two (Burlingame, 2004). Frequency distributions can assist in establishing the cause of a change in the 90th percentile value and AL exceedance. The frequency distribution presented in this Section provides an analysis of the lead sampling results collected since 1992. The data were sorted into several “bins” and percentile categories by lead concentration. The three “bins” that provide the best indication of whether or not CCT has been optimized are: (1) percent less than or equal to 5 µg/L, (2) 50th (median) percentile (µg/L), and (3) percent greater than 15 µg/L and less than or equal to 25 µg/L. Overall trends are also revealed by the frequency distribution data.

This section presents an updated frequency distribution to the October 2018 report and includes the second half of 2018 sampling for the Pequannock and Wanaque service areas.

2.1 Lead Frequency Distribution – Pequannock Service Area

For the Pequannock service area, the frequency distribution analysis was conducted for compliance sampling data collected in 1992, 1998, 2003, 2006, 2012, 2015, the two sampling periods in 2017, and the two sampling periods in 2018. Lead sampling rounds were also conducted by the City of Newark in 2002 and 2009; however, not enough samples were available in the Pequannock Gradient for a statistical analysis in those two years likely based on customer responsiveness.

Figure 2-1 provides an overview of the lead sampling compliance data from the ten (10) sampling events for the Pequannock service area for the different “bins” from less than 5 µg/L to greater than 50 µg/L. **Table 2-1** provides a summary of some statistical parameters based on the lead sampling compliance data, and **Table 2-2** provides an interpretation of the findings of the frequency distribution analysis for the Pequannock service area.



	1992	1998	2003	2006	2012	2015	2017 (1)	2017 (2)	2018 (1)	2018 (2)
≤ 5 (µg/L)	30.7%	59.2%	53.6%	56.0%	54.2%	60.0%	38.7%	39.3%	51.7%	36.0%
> 5 and ≤ 10 (µg/L)	24.8%	26.2%	21.4%	32.0%	41.7%	24.0%	17.3%	23.1%	30.0%	22.7%
> 10 and ≤ 15 (µg/L)	17.5%	7.8%	25.0%	12.0%	4.2%	4.0%	12.0%	8.5%	8.3%	6.7%
> 15 and ≤ 20 (µg/L)	5.1%	5.8%	0.0%	0.0%	0.0%	8.0%	8.0%	2.6%	3.3%	4.0%
> 20 and ≤ 25 (µg/L)	10.2%	1.0%	0.0%	0.0%	0.0%	4.0%	8.0%	3.4%	3.3%	2.7%
> 25 and ≤ 30 (µg/L)	5.1%	0.0%	0.0%	0.0%	0.0%	0.0%	6.7%	8.5%	0.0%	12.0%
> 30 and ≤ 50 (µg/L)	4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	9.4%	1.7%	10.7%
> 50 (µg/L)	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%	5.3%	5.1%	1.7%	5.3%

Figure 2-1 – Pequannock Service Area – Lead Sampling Data Percentage Frequency Distribution

Table 2-1 – Summary of Statistical Parameters for Pequannock Lead Sampling Data

Parameter	1992	1998	2003	2006	2012	2015	2017 (1)	2017 (2)	2018 (1)	2018 (2)
50th Percentile	8.5	4.0	4.8	4.1	5.0	0.0	7.4	7.8	0.0	7.6
75th Percentile	16.3	7.4	10.0	7.4	7.3	8.0	17.8	21.2	8.2	27.7
90th Percentile	26.8	12.3	12.2	9.5	9.7	15.8	29.8	36.0	14.8	39.5
Number of Samples (n)	137	103	28	25	24	25	75	117	60	75
Number of Samples >15 (n)	37	7	0	0	0	3	24	34	6	26
Percent > 15 and ≤ 25 (µg/L)	15.3%	6.8%	0.0%	0.0%	0.0%	12.0%	16.0%	6.0%	6.7%	6.7%
Maximum (µg/L)	60.4	23.0	14.2	11.5	14.0	25.0	137.0	77.7	52.6	72.2

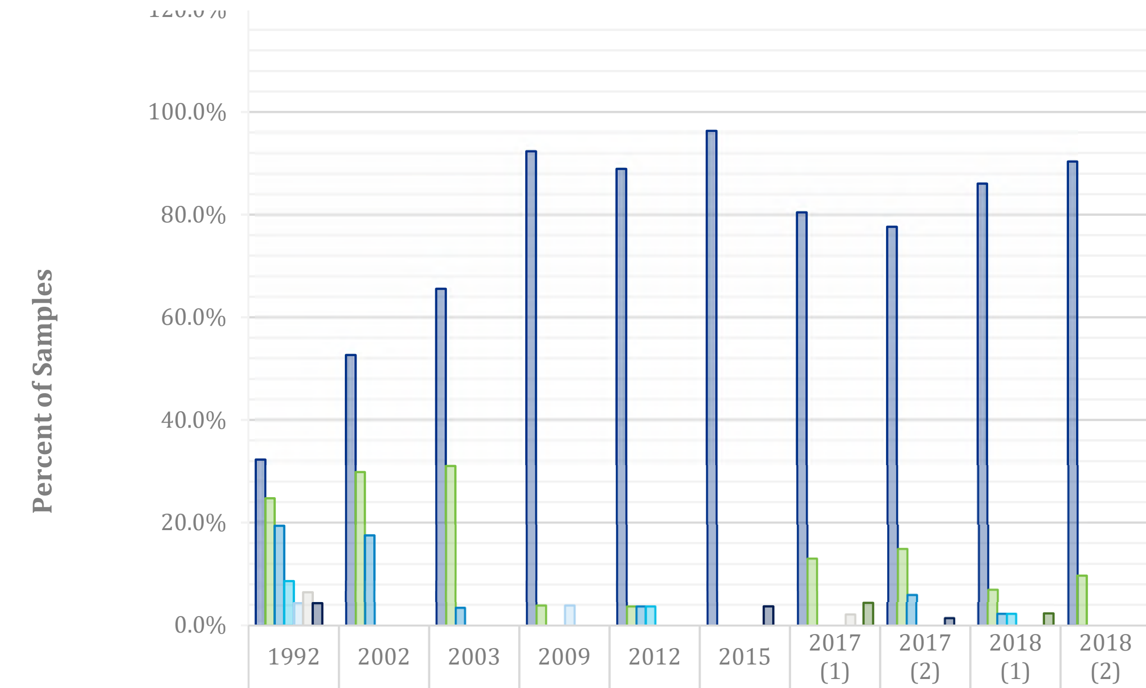
Table 2-2 – Pequannock Service Area Frequency Distribution Analysis

Data Category/Bin	What does it tell us?	Newark Pequannock Pb Results
Overall frequency distribution	Gives a comprehensive picture of sampling results and allows for comparisons over different periods of time.	The Pequannock WTP implemented sodium silicate chemical addition for CCT in 1997. The lead results from 1998 through 2012 reflect effective control of lead release. However, starting in 2015, lead levels returned to and, in some cases, exceeded 1992 levels. This points to a significant change in system behavior around 2015.
Less than or equal to 5 µg/L	Typically, optimization of a corrosion control treatment is signified by an increased percentage of values that are less than 5 µg/L. When water is treated to be less corrosive, or chemistry is modified to create a stable and insoluble lead compound, overall lead levels will decrease, thereby increasing the percentage of samples with the lowest lead concentrations.	The percentage of samples less than or equal to 5 µg/L increased after CCT was implemented (1997). However, this category only saw 60% of the samples at best, compared to optimized systems which typically see well above 80% of samples less than 5 µg/L. In 2017 and the second half of 2018, the number of samples less than 5 µg/L decreased significantly from 50-60% to slightly less than 40%.
50th percentile (µg/L)	The nature of the 90th percentile Action Level is such that it only takes a few samples to greatly affect the outcome of a monitoring period. One seemingly benign deviation in the sampling protocol can greatly skew the 90th percentile value. The 50th percentile is much more resilient and, as such, is a good indicator of the relative effectiveness of a CCT.	The 50^{th} percentile value decreased from 1992 levels by about half after CCT was implemented in 1997. However, the 50^{th} percentile nearly doubled in 2017 and the second half of 2018.
Greater than 15 µg/Land less than or equal to 25 µg/L	A small deviation within the 15 to 25 ppb range of samples above could put a system out of compliance. By improving the CCT, a system can provide a greater buffer between the 90th percentile values and the AL of 15 ppb, so as to lessen the effects of an unrepresentative sample.	Prior to implementation of CCT (1992), a significant percentage (15%) of the samples were in this range. After many years of no results being in this range, an uptick in results between 15 and 25 ppb began in 2015, continuing to the first half of 2017; and were still elevated thereafter but slightly less than between 2015 and the first half of 2017. This may be indicative that the most significant impact to the pipe scales may have peaked by early 2017, but this cannot be confirmed.

2.2 Lead Frequency Distribution – Wanaque Service Area

A frequency distribution analysis was conducted for compliance sampling data collected in 1992, 2002, 2009, 2012, 2015, the two sampling periods in 2017, and the two sampling periods in 2018 for the Wanaque service area. Lead sampling rounds were also conducted by the City of Newark in 1998 and 2003; however, not enough samples were available in the Wanaque Gradient for a statistical analysis in those two years likely based on customer responsiveness.

Figure 2-2 provides an overview of the lead sampling compliance data from the ten (10) sampling events for the Wanaque service area for the different "bins" from less than 5 μg/L to greater than 50 μg/L. **Table 2-3** provides a summary of some statistical parameters based on the lead sampling compliance data, and **Table 2-4** provides an interpretation of the findings of the frequency distribution analysis for the Wanaque service area.



	1992	2002	2003	2009	2012	2015	2017 (1)	2017 (2)	2018 (1)	2018 (2)
≤ 5 (μg/L)	32.3%	52.6%	65.5%	92.3%	88.9%	96.3%	80.4%	77.6%	86.0%	90.3%
> 5 and ≤ 10 (μg/L)	24.7%	29.8%	31.0%	3.8%	3.7%	0.0%	13.0%	14.9%	7.0%	9.7%
> 10 and ≤ 15 (μg/L)	19.4%	17.5%	3.4%	0.0%	3.7%	0.0%	0.0%	6.0%	2.3%	0.0%
> 15 and ≤ 20 (μg/L)	8.6%	0.0%	0.0%	0.0%	3.7%	0.0%	0.0%	0.0%	2.3%	0.0%
> 20 and ≤ 25 (μg/L)	4.3%	0.0%	0.0%	3.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
> 25 and ≤ 30 (μg/L)	6.5%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%
> 30 and ≤ 50 (μg/L)	4.3%	0.0%	0.0%	0.0%	0.0%	3.7%	0.0%	1.5%	0.0%	0.0%
> 50 (μg/L)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	2.3%	0.0%

Figure 2-2 – Wanaque Service Area – Lead Sampling Data Percentage Frequency Distribution

Table 2-3 – Summary of Statistical Parameters for Wanaque Lead Sampling Data

Parameter	1992	2002	2003	2009	2012	2015	2017 (1)	2017 (2)	2018 (1)	2018 (2)
50th Percentile	6.6	4.6	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75th Percentile	14.2	9.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90th Percentile	25.7	11.2	8.4	0.0	6.2	2.0	7.4	8.7	7.0	4.1
Number of Samples (n)	93	114	29	26	27	27	46	67	49	31
Number of Samples >15 (n)	22	0	0	1	1	1	3	1	2	0
Percent > 15 and ≤ 25 (µg/L)	12.9%	0.0%	0.0%	3.8%	3.7%	0.0%	0.0%	0.0%	2.3%	0.0%
Maximum (µg/L)	49.4	14.9	12.3	24.6	19.0	37.0	84.0	46.1	182.0	9.3

Table 2-4 – Wanaque Service Area Frequency Distribution Analysis

Data Category/Bin	What does it tell us?	Newark Wanaque_Pb Results
Overall frequency distribution	Gives a comprehensive picture of sampling results and allows for comparisons over different periods of time.	The Wanaque WTP implemented zinc orthophosphate chemical addition for CCT treatment in the mid 1990s. Between 1992 and 2018, lead sampling results for the Wanaque service area shifted in multiple “bins” (ranges). The 1992 sampling was prior to the CCT treatment improvements. These results point to CCT effectiveness as the cause of a significant decrease in action level beginning in the early 2000s and a shift in the percentage of results into lower bins.
Less than or equal to 5 µg/L	Typically, optimization of a corrosion control treatment is signified by an increased percentage of values that are less than 5 µg/L. When water is treated to be less corrosive, or chemistry is modified to create a stable and insoluble lead compound, overall lead levels will decrease, thereby increasing the percentage of samples with the lowest lead concentrations.	Between 1992 and 2018, there was a large increase in % of samples in this category. Where 1992 saw 32% of samples in this category, 2017 and 2018 sampling saw an increase to an average of 84% between the four sampling pools for lead results less than or equal to 5 ppb. This can again be tied to CCT treatment of zinc orthophosphate. Typically, optimized systems have a majority of sample results (>80%) in the category of <5 ppb.

Data Category/Bin	What does it tell us?	Newark Wanaque_Pb Results
50th percentile (µg/L)	The nature of the 90th percentile Action Level is such that it only takes a few samples to greatly affect the outcome of a monitoring period. One seemingly benign deviation in the sampling protocol can greatly skew the 90th percentile value. The 50th percentile is much more resilient and, as such, is a good indicator of the relative effectiveness of a CCT.	The 50th percentile value decreased from 6.6 in 1992 to zero (0) in in 2009, and has remained as such ever since indicating effectiveness of the zinc orthophosphate CCT treatment.
Greater than 15 µg/L and less than or equal to 25 µg/L	A small deviation within the 15 to 25 µg/L range could put a system out of compliance. By improving the CCT, a system can provide a greater buffer between the 90th percentile values and the AL of 15 µg/L, so as to lessen the effects of an unrepresentative sample.	There was a large decrease in the number of results in this category after the initial sampling round in 1992, which was prior to implementation of CCT. In 2009, 2012 and first half of 2018, there was a slight increase in this category, which could indicate sampling variability but not definitively. Overall, occurrences of lead levels above the action level decreased significantly indicating the effectiveness of the CCT treatment.

2.3 Service Area Comparison

When separating the LCR compliance sampling data for the Pequannock and Wanaque Gradients, it is clear from the results of the individual lead frequency distribution analyses that a large majority of the lead exceedances have occurred in the Pequannock service area. The frequency of lead exceedances in Pequannock alone has triggered the lead AL exceedances for the City of Newark since the first half of 2017. If the Pequannock and Wanaque Gradients were regulated independently, the Wanaque service area was in compliance with the Lead and Copper Rule from 2002 to present with 90th percentile values ranging from 0.0 to 11.2 µg/L over that period. Over that same period, the Pequannock 90th percentile values ranged from 9.5 to 39.5 µg/L. In the most recent sampling round, the second half of 2018, the Pequannock 90th percentile based on the verified LCR sampling pool was 39.5 µg/L and the Wanaque 90th percentile based on the verified LCR sampling pool was 4.12 µg/L.

If the customer requested samples are included in a 90th percentile calculation with the LCR compliance samples, the lead results in the first and second half of 2018 are higher but still indicate a major difference between the Pequannock and Wanaque Gradients. The Pequannock 90th percentile calculation for all samples (LCR compliance and customer requests) is 23.62 µg/L for the first half of 2018 and 46.74 µg/L for the second half of 2018. The Wanaque 90th percentile calculation for all samples (LCR compliance and customer requests) is 8.68 µg/L for the first half of 2018 and 9.61 µg/L for the second half of 2018. This calculation includes homes where the materials are not verified and are, therefore, not included in the official LCR compliance calculation. A 90th percentile calculation with customer requests is not a compliance requirement and is presented herein only to show the 90th percentile with an expanded pool of data.

The historic LCR compliance sampling data, as well as the data recently collected as part of this study, show that the current CCT for the Wanaque service area is able to consistently reduce lead levels in the drinking water to below the lead AL.

Due to the determination that the Pequannock system is triggering the lead AL exceedances for the City of Newark, the study on the Pequannock system was prioritized and submitted in draft form in October 2018 to the NJDEP and submitted as final in March 2019. The Pequannock report evaluated the cause of the elevated lead levels and provided recommendations for reducing lead levels in the Pequannock system, which are currently being implemented.

Since, as a whole, the entire City of Newark is not currently meeting the lead AL due to the Pequannock/Wanaque combined reporting, a more detailed report was requested by NJDEP providing further analysis on the Wanaque Gradient, including sequential sampling and pipe scale analyses. Based on the analyses herein, recommendations for optimization of the CCT in the Wanaque Gradient and recommendations to reduce the public's exposure to lead in drinking water in the Wanaque service area are provided in Section 6.

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Section 3

Water Quality

Historic water quality data was obtained from NJDEP Drinking Water Watch (as of June 12, 2019) and is summarized in this section. Data from PWSID NJ0714001 (Newark Water Department) and PSWID NJ1613001 (NJDWSC – Wanaque North) were used. Data were also obtained from Newark's WQP sampling locations in the Wanaque Gradient between July 2016 and April 2019.

The following subsections review the water quality of the Wanaque Gradient's point of entry (POE) and within Newark's distribution system.

3.1 Wanaque Gradient Point of Entry (POE) Water Quality Data

This section provides water quality data and analyses pertinent to the analysis of corrosion control treatment.

3.1.1 Belleville Data

To compare with the Pequannock water supply entering Newark's distribution system, silica, pH and orthophosphate were evaluated at the Belleville POE. Silica data was provided by NJDWSC for the raw water entering the Wanaque WTP. Raw water silica was analyzed on a quarterly basis between 2016 and 2018. Silica concentrations appear to be seasonal, similar to Pequannock, with higher concentrations in the winter and lower concentrations in the summer, with an average silica concentration of approximately 2 to 3 mg/L.

NJDWSC also provided pH and orthophosphate data between July 2016 and December 2018 leaving the Belleville Complex. This data is summarized in **Table 3-1**. **Figure 3-1** demonstrates the pH and orthophosphate trends between July 2016 and December 2018.

Table 3-1 – Water Quality Ranges for Wanaque POE and Raw Water Silica

Sample ID	Silica (mg/L) – Raw	pH - Belleville	Orthophosphate (mg/L as PO_4) - Belleville
minimum	0.74	7.38	1.26
average	2.03	7.78	1.76
maximum	3.53	8.48	2.88

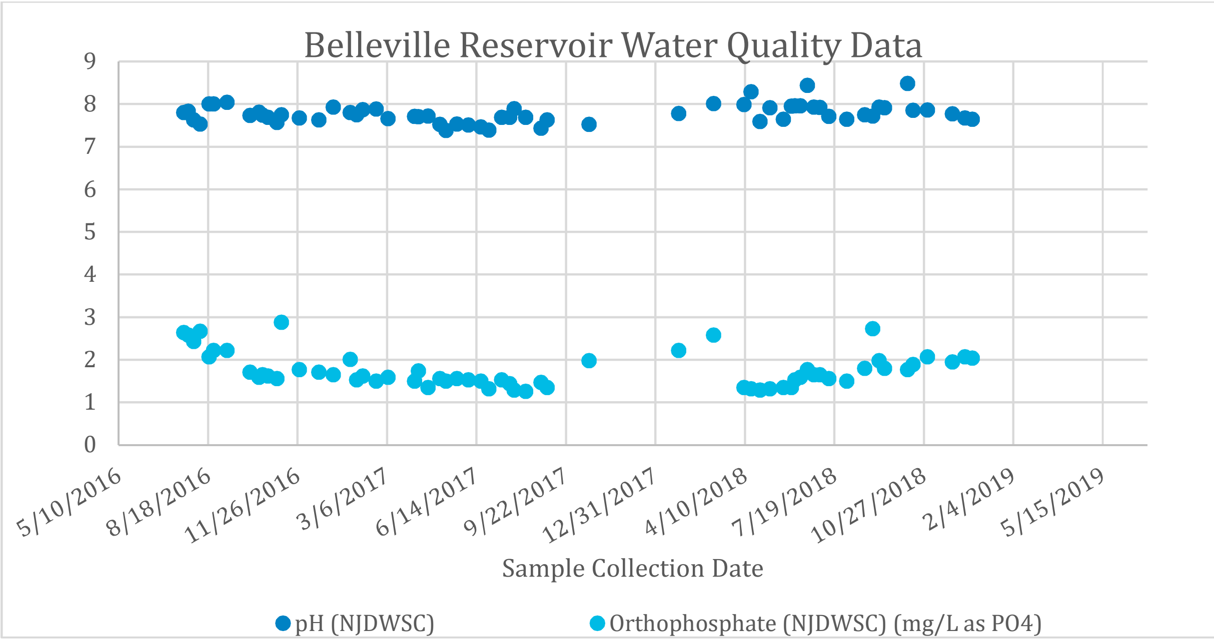


Figure 3-1 – Belleville Water Quality Data Trend

The data indicates that NJDWSC maintains a fairly consistent pH and orthophosphate residual at Newark's POE at approximately 7.8 and 1.76 mg/L (as PO_4), respectively, from the Wanaque system with occasional variations in pH or orthophosphate.

3.2 Wanaque Gradient Distribution System Water Quality Data

As mentioned in Section 1, Newark has been monitoring WQPs since July 2016 on a regular basis at several sampling locations. This includes points of entry into the distribution system (Sample House (PWTP), [redacted], Montclair Re-chlorination Station and the Belleville Reservoir Complex) on a bi-weekly basis and 25 sampling locations in the distribution system on a quarterly basis. The sampling locations for monitoring Newark's distribution system WQPs were presented in **Figure 1-14**. There are 13 WQP sampling locations in the Pequannock service area (labeled with "P") and 12 WQP sampling locations in the Wanaque service area (labeled with "W"). However, based on the addresses provided for these sample locations, it appears that the following WQPs may have been labeled incorrectly, and are currently being modified with NJDEP.

- 2W – Labeled as Wanaque but in the Pequannock service area
- 8W – Labeled as Wanaque but in the Pequannock service area
- 11W – Labeled as Wanaque but in the Pequannock service area
- 10P – Labeled as Pequannock but in the Wanaque service area

The water quality data for the 25 WQP sampling locations in the distribution system were provided between July 2016 and December 2018. The WQPs for the distribution system are reported on a quarterly basis. **Table 3-2** summarizes statistics for pH, alkalinity, orthophosphate and silica at the WQP distribution sampling locations in the Pequannock and Wanaque Gradients. Sampling locations 2W, 8W and 11W are included with Pequannock's data and sampling location 10P is included with Wanaque data based on their physical locations in the system.

Table 3-2 – Pequannock and Wanaque Gradient WQP Distribution System Water Quality (July 2016 – December 2018)

	Pequannock			Wanaque		
Parameter	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**
pH	6.69	7.46	8.73	6.86	7.52	8.30
Alkalinity (mg/L as $CaCO_3$)	21.40	30.51	59.30	21.30	33.63	51.60
Orthophosphate (mg/L as PO_4)	ND	0.10	1.39	ND	0.52	2.37
Silica (mg/L as Silica)	3.70	6.21	8.80	1.24	4.94	8.19

As can be seen in **Table 3-2**, there are some similarities and some distinct differences between the water quality in the Pequannock Gradient and the Wanaque Gradient. Some observations include:

- The pH values are very similar between the Pequannock and Wanaque Gradients; however, the Wanaque Gradient appears to have a more consistent pH than the Pequannock Gradient.
- Average alkalinity in the Wanaque Gradient is slightly higher at 34 mg/L as $CaCO_3$ than the Pequannock Gradient at 31 mg/L as $CaCO_3$; however, the seasonal variations are similar.
- Orthophosphate residual is significantly higher in the Wanaque Gradient than the Pequannock Gradient, although lower on average than at the target dose of 1.8 mg/L to 2.2 mg/L as PO_4 at the POE leaving the Belleville Reservoir Complex**.** The Pequannock Gradient occasionally gets water with orthophosphate from one of its interconnections with PVWC or Jersey City which may explain the PO_4 concentrations that appear in limited samples in the Pequannock.
- The silica concentration is significantly higher for the Pequannock Gradient on average than the Wanaque Gradient, although the maximum values are similar.

3.2.1 Wanaque and Pequannock Mixing

There are two known ways that water can flow from the Pequannock Gradient to the Wanaque Gradient. Specifically, there are forty-seven (47) division gate valves and eight (8) pressure regulating valves within the Newark distribution system that can send water from Pequannock to Wanaque on an as needed basis. These valves are closed under normal operating conditions and are intended to separate Wanaque and Pequannock Gradients. Division gates are operated manually whereas pressure regulating valves open and close automatically based on a set pressure differential between the two gradients. These valves provide added resiliency to

Newark's water distribution system as they can divert water to areas in need on a temporary basis, such as a water main break, low flow condition, or emergency such as a fire. Since the Wanaque Gradient is lower (165 feet) compared with the Pequannock Gradient (over 200 feet), water will typically move from the higher Pequannock Gradient to the lower Wanaque Gradient and not from Wanaque to Pequannock unless there were to be a significant drop in pressure in the Pequannock Gradient. From November 2018 through January 2019, the City investigated and evaluated the pressure reducing valves and division gate valves to determine if there were any leaking or malfunctioning valves within the system. It was reported that none of the valves were leaking; however, approximately 6 division gate valves were found to be partially open. Any division gate valve that was found partially open was closed by Newark during this period. It is important to note that the pressure regulating valves must remain active in case of system emergency conditions but are normally in the closed position.

After the division gates were closed, there was a noticeable change in water quality parameters, specifically an increase in orthophosphate residual and decrease in silica concentrations, in several of the WQP locations in the Wanaque Gradient. This can be seen in **Tables 3-3 and 3-4,** which provide the average values for pH, alkalinity, orthophosphate and silica at each Pequannock and Wanaque WQP sampling locations, respectively, from July 2016 to December 2018 and then from March and April 2019 at specific Wanaque locations in **Table 3-4**.

As shown in **Table 3-3**, the WQP sampling location 10P[redacted]) highlighted in green is confirmed to be sampling water from the Wanaque Gradient and not the Pequannock Gradient as previously thought. This sampling location is proposed to be changed to a Wanaque WQP.

In **Table 3-4**, the highlighted green rows are suspected to be sampling water from the Pequannock Gradient and not the Wanaque Gradient. Even with all of the division gates closed, WQP sampling locations 2W, 8W and 11W had very little to no orthophosphate residual and higher than typical Wanaque silica concentrations.

The water quality data collected after all of the division gates were checked and closed show an appreciable increase in orthophosphate residual and decrease in silica concentration in the WQP locations 3W, 4W, 5W, 6W, 7W, 10W and 12W. This is represented by the yellow highlighted cells. As a result, it is suspected that these sampling locations in the Wanaque Gradient had been "Likely Supplemented by Pequannock" Prior to the closure of the division gates. These locations are indicated on the map shown in **Figure 3-2**.

Based on the lead levels in customer taps as presented in Section 2, the water quality in the Wanaque Gradient, including the lower levels of orthophosphate found in some areas, does not appear to have been impacted to result in an increase in lead levels in the Wanaque Gradient. Once the division gates were closed, the lower levels of orthophosphate seen in portions of the Wanaque Gradient appear to have been addressed.

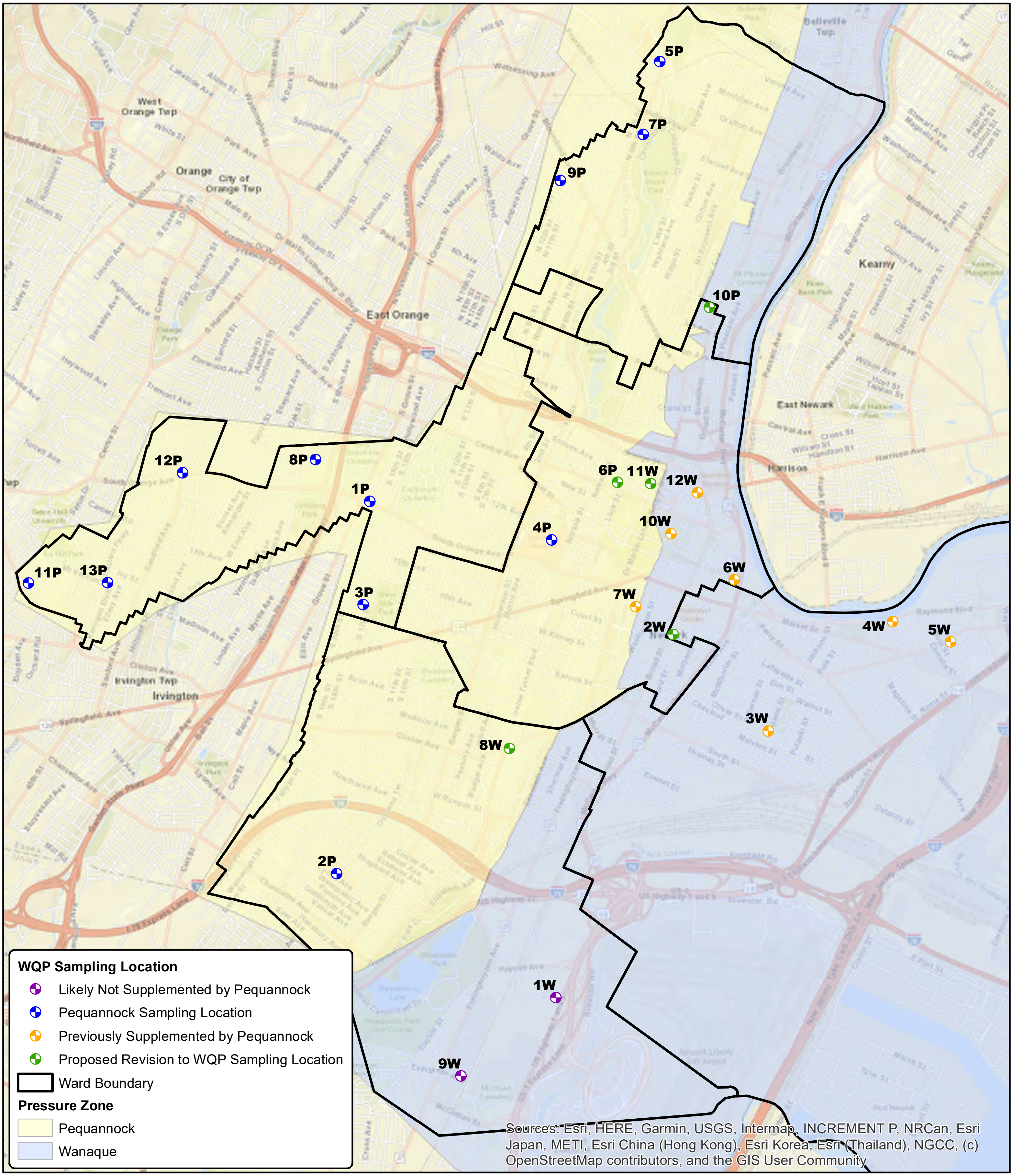
In addition to the above, with orthophosphate now being added in the Pequannock Gradient, any blending of the two sources should not result in diminished orthophosphate residuals.

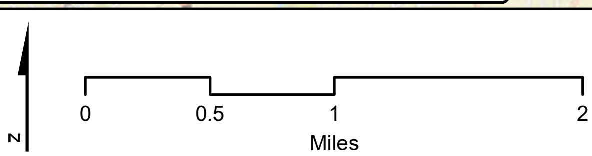
Table 3-3 - Pequannock WQP Sampling Locations Summary (July 2016 - December 2018)

Pequannock							
Sample ID	WQP Sampling Locations	Data Used	pH	Alkalinity (mg/L as CaCO3)	Orthophosphate (PO4)	Silica (mg/L as Silica)	Comments
			average	average	average	average	
TH	Sample House, PWTP	2016-2018	7.11	25.67	0.03	7.95	POE Pequannock
VR	Montclair Rechlorination Stn. [redacted]	2016-2018	7.25	29.75	0.01	6.03	POE Pequannock
1P	Senior Home, 545 Orange Street	2016-2018	7.45	29.49	Not measured	6.66	Keep Pequannock WQP
2P	Beth Israel Hospital, 201 Lyons Avenue	2016-2018	7.56	29.66	Not measured	6.31	Keep Pequannock WQP
3P	South 17th School, 619 South 17th Street	2016-2018	7.37	29.50	Not measured	6.53	Keep Pequannock WQP
4P	Univeristy Hospital, 16 Bergen Street	2016-2018	7.33	29.44	Not measured	6.14	Keep Pequannock WQP
5P	Stephen Crane Village, 4 Steven Crane Plaza	2016-2018	7.61	32.96	Not measured	5.93	Keep Pequannock WQP
6P	City of Newark, 239 Central Avenue	2016-2018	7.41	30.54	Not measured	6.34	Keep Pequannock WQP
7P	Senior House 801 North 6th Street	2016-2018	7.38	29.49	Not measured	6.42	Keep Pequannock WQP
8P	Bradley Courts, 46N Munn Avenue	2016-2018	7.54	29.44	Not measured	6.14	Keep Pequannock WQP
9P	Columbus Hospital 495N 13th Street	2016-2018	7.30	29.67	Not measured	6.48	Keep Pequannock WQP
10P	Broadway House, 298 Broadway	2019 WQP Study	7.67	25.80	1.68	4.20	Change to Wanaque WQP
11P	Ivy Hill Liquors 521 Ivy Hill Plaza	2016-2018	7.65	30.89	Not measured	6.02	Keep Pequannock WQP
12P	Sanford Avenue Pharmacy, 1041 South Orange Avenue	2016-2018	7.42	32.39	Not measured	6.09	Keep Pequannock WQP
13P	Sub City, 81 Mount Vernon Place	2016-2018	7.50	31.11	Not measured	5.97	Keep Pequannock WQP

Table 3-4 - Wanaque WQP Sampling Locations Summary (July 2016 - December 2018; March-April 2019)

Wanaque							
Sample ID	WQP Sampling Locations	Data Used	pH	Alkalinity (mg/L as CaCO3)	Orthophosphate (PO4)	Silica (mg/L as Silica)	Comments
			average	average	average	average	
BR	Belleville Reservoir	2016-2018	7.58	41.60	1.48	2.53	POE Wanaque
1W	Holiday Inn, 450 Route 1 & 9 South	2016-2018	7.81	40.38	1.41	2.66	Keep Wanaque WQP
2W	Newark City Hall, 930 Broad Street	2016-2018	7.42	32.41	0.09	5.72	Remove from WQP List - dual feeds to building
		Mar-Apr 2019	7.10	24.60	ND	5.93	
3W	Glamour's Salon, 251 Oliver Street	2016-2018	7.53	33.63	0.67	4.61	Keep Wanaque WQP
		Mar-Apr 2019	7.48	26.77	2.01	4.33	
4W	River Bank Auto Repairs, 638 Raymond Blvd	2016-2018	7.48	33.33	0.46	4.90	Keep Wanaque WQP
		Mar-Apr 2019	7.60	25.73	1.41	4.44	
5W	Hawkins School, 9 Hawkins Street	2016-2018	7.43	32.95	0.40	4.75	Keep Wanaque WQP
		Mar-Apr 2019	7.51	24.57	1.41	4.47	
6W	Seton Hall Law School, 1109 Raymond Blvd	2016-2018	7.59	32.34	0.45	5.01	Keep Wanaque WQP
		Mar-Apr 2019	7.53	25.50	1.38	4.42	
7W	Newark Health Service, 94 William Street	2016-2018	7.43	31.41	0.09	5.88	Keep Wanaque WQP
		Mar-Apr 2019	7.57	27.07	1.47	4.39	
8W	Firehouse, 360 Clinton Avenue	2016-2018	7.48	31.88	0.15	5.89	Change to Pequannock WQP - location
9W	Associated Humane Society, 124 Evergreen Avenue	2016-2018	7.60	40.42	0.76	3.26	Keep Wanaque WQP
10W	Rutgers University, 190 University Avenue	2016-2018	7.41	30.92	0.33	6.08	Keep Wanaque WQP
		Mar-Apr 2019	7.53	26.47	1.80	4.38	
11W	Senior Citizen Home, 9 Summit Street	2016-2018	7.42	30.74	0.04	5.96	Remove from WQP List - dual feeds to building
		Mar-Apr 2019	6.97	20.97	ND	6.78	
12W	Newark Library, 5 Washington Avenue	2016-2018	7.52	31.77	0.12	5.70	Keep Wanaque WQP
		Mar-Apr 2019	7.32	24.67	1.38	4.62	





Newark WQP Sampling Locations

Potential Influence from Pequannock on Wanaque Water Quality

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Figure 3-2

3.3 Chloride-to-Sulfate Mass Ratio

Galvanic corrosion on lead solder joints on copper plumbing can be affected by chloride concentrations, as indicated by the chloride to sulfate mass ratio (CSMR). CSMR is calculated by dividing the average chloride concentration by the average sulfate concentration (Nguyen, Stone, Clark, & Edwards, 2010). The literature reports a "threshold" CSMR value of 0.5, above which galvanic corrosion of lead solder on copper piping can increase. The greatest concerns, however, are utilities with lead solder joints that change their water chemistry to increase CSMR from below 0.5 to above 0.5 as indicated in the Water Research Foundation (WRF) 4088 Study (Nguyen, Stone, Clark, & Edwards, 2010).

The researchers in the WRF study observed that in waters with CSMR equal to or less than 0.5, very low corrosion rates were observed. High chloride relative to sulfate, yielding CSMRs above 0.5, tended to increase galvanic corrosion of lead solder connected to copper pipe. They also observed, statistically, that as relative concentrations of chloride to sulfate increased in the water supply, the 90th percentile lead concentration generally increased. In their bench-scale experiments, waters with high CSMR were consistently more aggressive in increasing lead leaching from solder galvanically connected to copper.

Historic chloride and sulfate data are not available for Newark's Wanaque Gradient distribution system. However, chloride and sulfate data from the same water source are available just downstream of the Wanaque WTP. Chloride and sulfate concentrations are not expected to change substantially throughout a distribution system, so they would be expected to be similar within Newark's Wanaque Gradient. Based on an average chloride concentration of 46.0 mg/L and an average sulfate concentration of 14.2 mg/L, Wanaque's average CSMR is 3.2. Although Wanaque's CSMR is above the 0.5 threshold, there are many systems that operate with similar or higher CSMRs that do not have high lead levels or AL exceedances. The likely reason for this is that much of the solder exposed to the water may have been released at very low rates over decades. The WRF research focused on simulating release of lead from solder that was abruptly subjected to high CSMR water. This is corroborated by full-scale experience where the CSMR changed abruptly due to a process or water quality change (e.g., systems changing form alum to PACl or alum to ferric chloride). In these cases, the "baseline" condition was a relatively low CSMR (however, often times greater than 0.5), and the operation change caused a sudden increase in CSMR, which contributed to lead release and spikes in tap water sampling results (Nguyen, Stone, Clark, & Edwards, 2010).

Data were obtained from 1993 to 2018 from NJDEP WaterWatch for PSWID NJ1613001, under TP003006, which represents the chloride and sulfate concentrations for a system downstream of the Wanaque WTP. The only data available for chloride and sulfate is one data point per year which is not sufficient to make a determination on whether or not the CSMR is increasing.

Based on discussions with the plant operators, no major treatment changes have been made in the last 20+ years that would impact chloride and sulfate concentrations.

Research and field experience indicate that orthophosphate can be effective in reducing lead release in conditions of galvanic corrosion, which is typically marked by a combination of low pH and high CSMR at the solder surface (Nguyen, Stone, Clark, & Edwards, 2010)). The Wanaque Gradient is already dosing zinc orthophosphate in the drinking water.

Section 4

Sequential Sampling

The City of Newark conducted sequential sampling at seven locations in the Wanaque Gradient in December 2018, January 2019, April 2019 and May 2019. The purpose of this effort was to compare the Wanaque Gradient with the sequential sampling previously performed in the Pequannock Gradient. In addition, the sampling was conducted to evaluate potential sources of lead that may exist within the service line and premise plumbing from the service connection in the street to the drinking water tap in the house. Sequential sampling is an additional tool to assist in developing an understanding of the system as part of the CCT optimization. The sources of lead at the tap measured in sequential samples include lead service lines, lead-based materials contained in the premise piping (e.g., leaded solder, brass/bronze fittings, galvanized piping) and faucets.

4.1 Sequential Sampling Program Protocol

The sequential sampling program consisted of collecting the full volume of water between the kitchen faucet and the water main in small increments allowing for the isolation of water from various plumbing components, such as, but not limited to, fixtures, valves, pipe materials and meters. A memorandum dated September 10, 2018 by CDM Smith titled "Sequential Sampling Program Protocol for Tracking Lead in Drinking Water" provided the protocol for performing the sequential sampling.

In general, the sequential sampling process consisted of the following:

1. **Site Audit -** An initial visit to each home was conducted to document the cold-water piping, beginning at the faucet and traced back towards the water main in the street. This was used to calculate the volume in the water service line and determine the number and timing of samples needed for collection.

2. **Sample Collection and Analysis -** Sequential sampling is conducted after a stagnation period, between 6 to 12 hours, per the Lead and Copper Rule requirements. A 10-minute flush is conducted, without removing the faucet aerators, unless otherwise noted, prior to the stagnation period. Samples are taken at the kitchen sink in increments of 500 mL, or as determined by the site audit. A flushed sample is also taken at the end of the sequential program to test the water in the main. The faucet aerator was typically not removed for the flushing, with an exception described later in this section. The aerator was generally removed for sampling, depending on its accessibility. Samples were analyzed for the following information:

    - *pH (first sample, a middle sample, and flushed final sample measured in the field)*

    - *Temperature (first sample, a middle sample, and flushed final sample measured in the field)*

- *Free chlorine (first sample, a middle sample, and flushed final sample measured in the field)*
- *Total Lead*
- *Dissolved Lead*
- *Total Copper*
- *Silica Residual (SiO_2) (first sample, a middle sample, and flushed final sample)*
- *Orthophosphate (mg/L as P) (first sample, a middle sample, and flushed final sample)*
- *Alkalinity (first sample, a middle sample, and flushed final sample)*
- *Conductivity (first sample, a middle sample, and flushed final sample)*

3. **Data Evaluation** – Once the samples were analyzed, the profile was plotted with cumulative volume on the X-axis and lead results on the Y-axis. Specific plumbing components were located along the service volume axis and the plumbing components most contributing to high lead values were noted.

4. **Monitoring** – If the CCT is modified, the sequential sampling program would be performed on a regular basis to ascertain the effectiveness of the new/modified CCT treatment.

4.2 Results of Sequential Sampling in the Wanaque Gradient

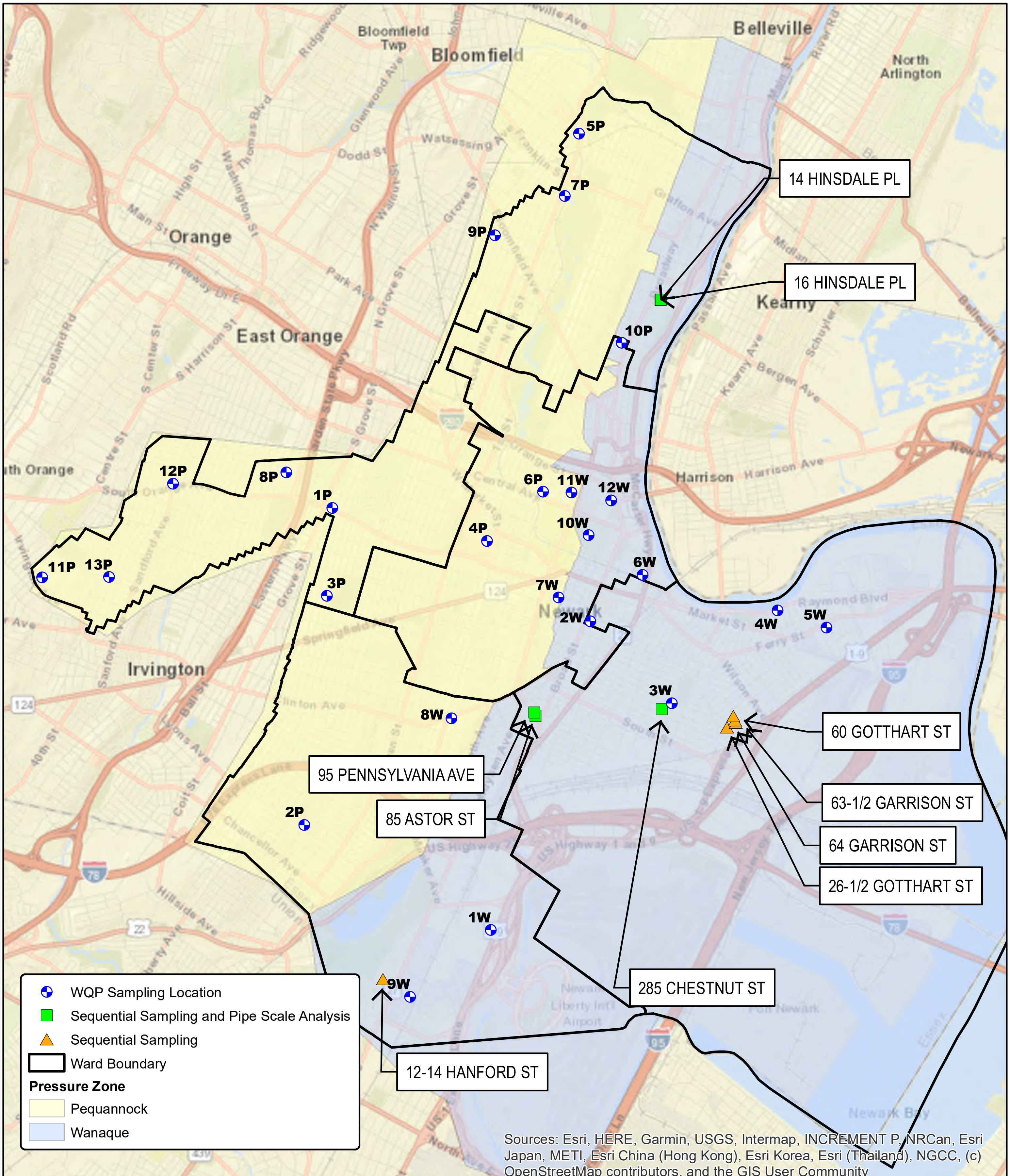
On December 14, 2018, CDM Smith coordinated sequential sampling for two residential locations in the Wanaque Gradient:

- 95 Pennsylvania Avenue (East Ward) (Also sampled post-LSL removal on January 19, 2019)
- 14 Hinsdale Place (North Ward) (Also sampled post-LSL removal on January 19, 2019)

The locations of these homes are shown in **Figure 4-1**. Sequential sampling was performed as described in Section 4.1 with the faucet aerator left on for flushing, but removed for sampling. Once the sequential sampling was complete, the lead service lines were replaced and portions of the service lines were sent to the EPA for scale analysis. On January 19, 2019, sequential sampling was again performed at these two residential locations, approximately 1 month after the lead service line had been replaced with copper. In the second sampling at each home, the aerator was removed prior to flushing and kept off for the duration of the sampling.

Additionally, sequential sampling was performed on January 11, 14, and 21, 2019 at the following addresses with LSLs:

- 26 ½ Gotthardt Street (East Ward)
- 285 Chestnut Street (East Ward)



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Sequential Sampling and Scale Analysis Locations in Wanaque

CDM Smith

Figure 4-1

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- 64 Garrison Street (East Ward)
- 63 ½ Garrison Street (East Ward)
- 16 Hinsdale Place (North Ward)

Lastly, sequential sampling was performed at the following locations to address the remaining actions required by DEP, dated April 18, 2019. These locations have LSLs and were sampled on April 16 and May 17, 2019.

- 85 Astor Street (East Ward)
- 12-14 Hanford Street (South Ward)
- 60 Gotthardt Street (East Ward)

Upon review of the results for the Wanaque sequential sampling in February 2019, it was discussed with DEP that the following would be implemented when conducting the sequential sampling in April and May of 2019:

- Smaller aliquots of samples would be collected for the first liter to assist in pinpointing more specific components of the plumbing that may have elevated lead levels
- Dissolved lead would not be analyzed
- Implementation of additional quality control processes for field pH measurements

The locations of the ten (10) sequential sampling sites are shown on **Figure 4-1**. The faucet aerator was removed by Newark staff prior to the flushing process and remained off until sampling was completed for 95 Pennsylvania Avenue, 85 Astor Street, 12-14 Hanford Street, and 14 Hinsdale Place. The aerator was not confirmed to be removed by Newark staff for flushing for 64 Garrison Street, 63 ½ Garrison Street and 60 Gotthardt Street. The aerator was, however, removed during sampling., The aerator was fixed to the faucet fixture for, 285 Chestnut Street, 16 Hinsdale Place, and 26 ½ Gotthardt Street, and therefore was neither removed during the flushing process nor for sample collection.

The samples were analyzed for total lead (and sometimes soluble lead) and copper and the results are summarized by location in the subsections that follow**.** The background water quality was analyzed at the start of the testing (first sample or second sample), the middle of the testing (middle samples) and after a 10-minute flush (flushed sample).

For each location, lead is plotted against the cumulative water volume in a profile to identify lead contributions from different plumbing components and materials. The difference between the total lead and soluble lead, where tested, is insoluble or particulate lead. Particulate lead can be a result of scouring of deposits off the pipe wall disturbing the scale layers that have formed over time or from particulates collecting in the aerator or fixtures. Soluble lead is dissolved lead that has leached from the piping into the water. For each home's profile, the plumbing fixtures and materials are shown above the graph for correlation to the samples.

4.2.1 South Ward – 95 Pennsylvania Avenue (Previously East Ward)

The address 95 Pennsylvania Avenue is located in the South Ward. The mapping in **Figure 4-1** shows the address in the East Ward based on the previous ward boundaries. It was estimated that 95 Pennsylvania Avenue needed thirteen (13) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and lead solder with copper indoor plumbing and was sampled before the lead service line replacement (LSLR) and after the LSLR. A portion of the lead service line was sent to the EPA for a scale analysis. The following are the observations for the lead profile and water quality results for 95 Pennsylvania Avenue, as shown in **Tables 4-1** and **4-2** and **Figures 4-2** and **4-3**.

- The highest lead levels at this address were found in the interior plumbing components, including the faucet hosing. For the first sequential sampling, before the LSLR, soluble lead peaked at 23.4 µg/L and total lead at 185 µg/L in the first sample (on the faucet hosing and interior plumbing components). For the second sequential sampling (post-LSLR), soluble lead peaked at 19.8 µg/L in the 12^{th} sample and the total lead peaked at 108 µg/L in the first sample. This appears to be all particulate lead and the homeowner should continue to flush without the aerator and replace the aerator.

- A spike in lead levels was seen in the 5^{th} liter in the first sequential sampling (pre-LSLR) at 31.4 µg/L and in the 6^{th} liter in the second sequential sampling (post-LSLR) at 38.3 µg/L. This could potentially be from a brass corp stop with lead or from a disturbance, possibly construction in the area.

- Significant particulate lead was found at this address in the first draw samples in both sequential sampling events. For the first sequential sampling, the aerator was removed on site prior to collecting samples but after flushing and stagnation. For the second sequential sampling, the aerator was removed prior to flushing and the stagnation period and remained off until sampling was completed.

- Silica concentrations were an average of 3.54 mg/L as SiO_2 for the first sequential sampling, which coincides with the Wanaque WQP ranges. Silica testing was not performed for the second sequential sampling.

- Orthophosphate measurements were an average of 1.45 mg/L as PO_4 for the first sequential sampling and 2.97 mg/L as PO_4 for the second sequential sampling, which coincides with the Wanaque WQPs measured in the distribution system. Note that the orthophosphate analysis for the first sequential sampling event was performed "out of hold," or after the 48 hour required analysis time for a sample. It was performed within 72 hours of the sampling.

- Based on the water quality data collected at the tap, this location does not appear to have been significantly influenced by the Pequannock Gradient water at the time of the sampling events even though it is located on the border of the two gradients.

- The total copper in the first sequential sampling results ranged from ND to the maximum value of 0.239 mg/L (9^{th} sample). For the second sequential sampling, the total copper results ranged from ND to the maximum value of 0.350 mg/L (12^{th} sample).

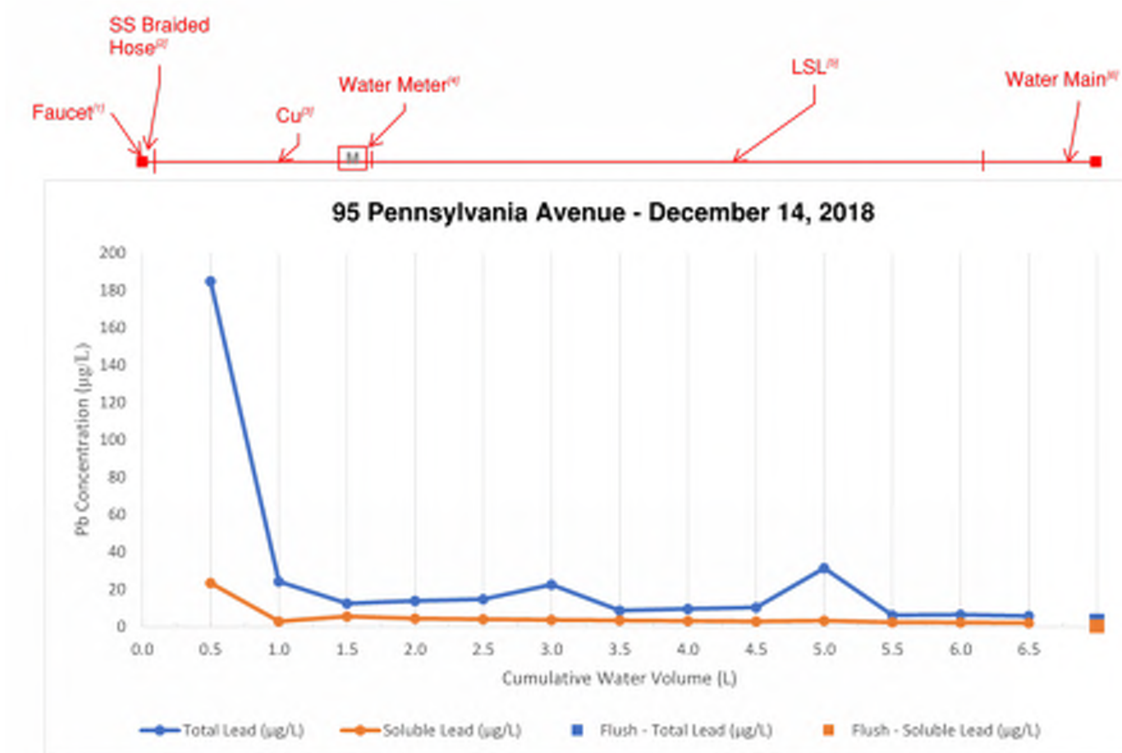
Table 4-1 – Water Quality Analysis at 95 Pennsylvania Avenue

Date of Sampling	Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
Before LSLR (12/14/18)	First Liter	N/A	N/A	N/A	33.0	251.0	3.75	0.396 (1.19 mg/L as PO_4)
	Middle Samples				31.0	252.0	3.64	0.503 (1.51 mg/L as PO_4)
	Flushed Sample				23.0	248.0	3.24	0.546 (1.64 mg/L as PO_4)
After LSLR (1/19/19)	First Liter	6.97	15.0	0.04	34.0	215.0	N/A	0.739 (2.22 mg/L as PO_4)
	Middle Samples	6.99	12.8	0.06	31.0	244.0		0.686 (2.06 mg/L as PO_4)
	Flushed Sample	7.07	8.1	0.56	25.0	243.0		1.54 (4.62 mg/L as PO_4)

[1]Values believed to be anomalous, see discussion section.

Table 4-2 – 95 Pennsylvania Avenue Lead Results

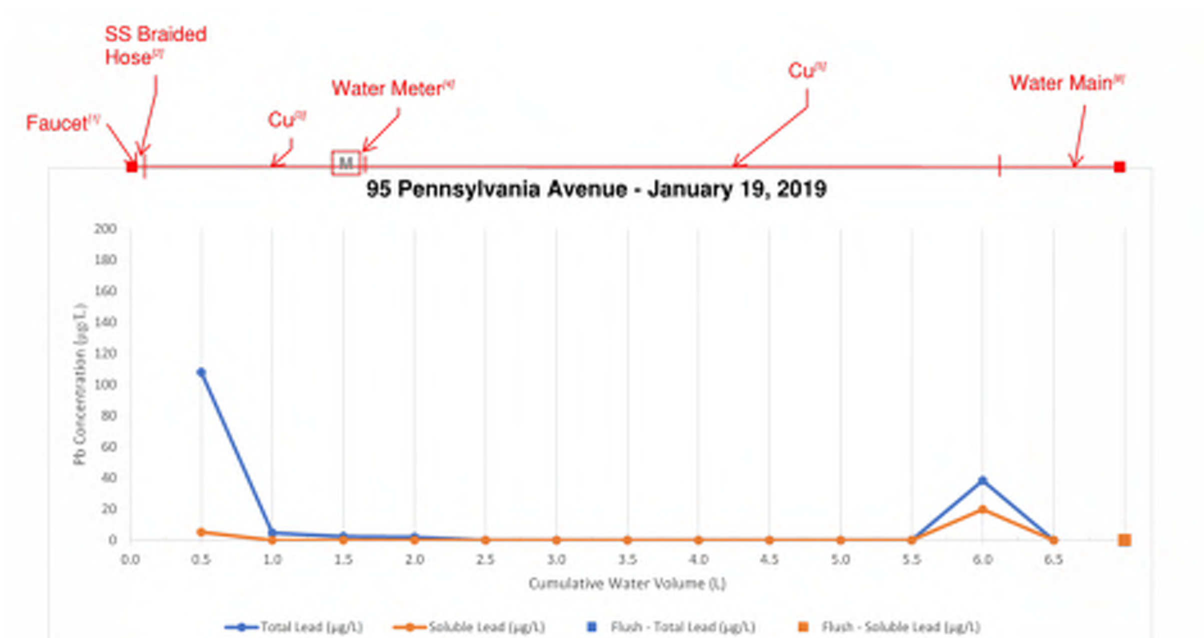
Sample ID	Before LSLR (12/14/2018)		After LSLR (01/19/2019)	
	Total Lead (µg/L)	Soluble Lead (µg/L)	Total Lead (µg/L)	Soluble Lead (µg/L)
1	185	23.4	108	5.24
2	24.2	2.86	4.75	< 2.0
3	12.5	5.52	2.40	< 2.0
4	13.8	4.41	2.06	< 2.0
5	14.7	4.00	< 2.0	< 2.0
6	22.6	3.63	< 2.0	< 2.0
7	8.68	3.37	< 2.0	< 2.0
8	9.53	3.07	< 2.0	< 2.0
9	10.3	2.94	< 2.0	< 2.0
10	31.4	3.31	< 2.0	< 2.0
11	6.14	2.38	< 2.0	< 2.0
12	6.43	2.21	38.3	19.8
13	5.74	2.04	< 2.0	< 2.0
Flushed	2.96	< 2.0	< 2.0	< 2.0



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Copper Pipe Segment, [4] Water Meter Location, [5] Lead Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-2 – 95 Pennsylvania Avenue Lead Profile – December 14, 2018



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Copper Pipe Segment, [4] Water Meter Location, [5] New Copper Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-3 – 95 Pennsylvania Avenue Lead Profile – January 19, 2019

- The pH measurements were an average of 7.01 in the sequential sampling event, which is lower than the Wanaque WQPs measured in the distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. pH measurement is seemingly simple, but in reality there are significant efforts beyond routine calibration required to obtain consistently accurate results. Electrodes can easily become scratched, deteriorated, or accumulate debris and require careful handling and storage. Subsequent testing of pH with 3 different electrodes at several locations found that one of three electrodes consistently produced significantly lower pH readings, while the remaining two electrodes provided pH readings within the range expected (7.0 to 7.7). As such, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.

- The flow rate was measured on site during the sampling. The first sampling event occurred using a flow rate of 0.51 gpm and the second sampling occurred using a flowrate of 0.45 gpm.

- After flushing the water at the faucet for 10 minutes, the soluble lead was non-detect (ND), and the total lead was 2.96 µg/L for the first sequential sampling. After the service line was replaced, both the soluble lead and total lead concentrations were ND in the flushed sample. As noted above, a spike in lead levels was seen in the 6th liter (or 12th sample). This may be the corp stop connection to the water main that was disturbed during the replacement. The homeowner should continue to flush the line after periods of stagnation. Newark can retest the 5th and 6th liter to confirm this is decreasing over time.

4.2.2 North Ward – 14 Hinsdale Place

It was estimated that 14 Hinsdale Place needed twenty (20) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and lead solder found on the copper indoor plumbing before the meter. This location was sampled before and after the LSLR. A portion of the lead service line was sent to the EPA for a scale analysis. The following are the observations for the lead profile results for 14 Hinsdale Place, as shown in **Tables 4-3** and **4-4** and **Figures 4-4** and **4-5**.

- The highest lead levels at this address were found in the interior plumbing components, including the faucet hosing and piping connected to the faucet. For the first sequential sampling, before the LSLR, the soluble lead peaked at 7.35 µg/L and total lead at 52.4 µg/L in the second sample (in the interior plumbing components after the faucet). For the second sequential sampling, after the LSLR, soluble lead peaked at 14.4 µg/L in the flushed sample and the total lead peaked at 17 µg/L in the fourth sample.

- Elevated amounts of particulate lead were found at this address the interior plumbing. For the first sequential sampling, the aerator was removed prior to collecting samples, but after flushing and stagnation. For the second sequential sampling, the aerator was removed prior to flushing and the stagnation period and remained off until sampling was completed.

Table 4-3 – Water Quality Analysis at 14 Hinsdale Place

Date of Sampling	Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
Before LSLR (12/14/18)	First Liter Sample	N/A			42.0	225.0	6.41	< 0.1 (< 0.3 mg/L as PO_4)
	Middle Samples				28.0	210.0	6.48	< 0.1 (< 0.3 mg/L as PO_4)
	Flushed Sample				28.0	214.0	6.57	< 0.1 (< 0.3 mg/L as PO_4)
After LSLR (1/19/19)	First Liter Sample	6.76	15.1	0.06	27.0	214.0	N/A	< 0.1 (< 0.3 mg/L as PO_4)
	Middle Samples	6.90	9.9	0.03	31.0	202.0		< 0.1 (< 0.3 mg/L as PO_4)
	Flushed Sample	6.82	8.9	0.98	30.0	211.0		0.702 (2.11 mg/L as PO_4)

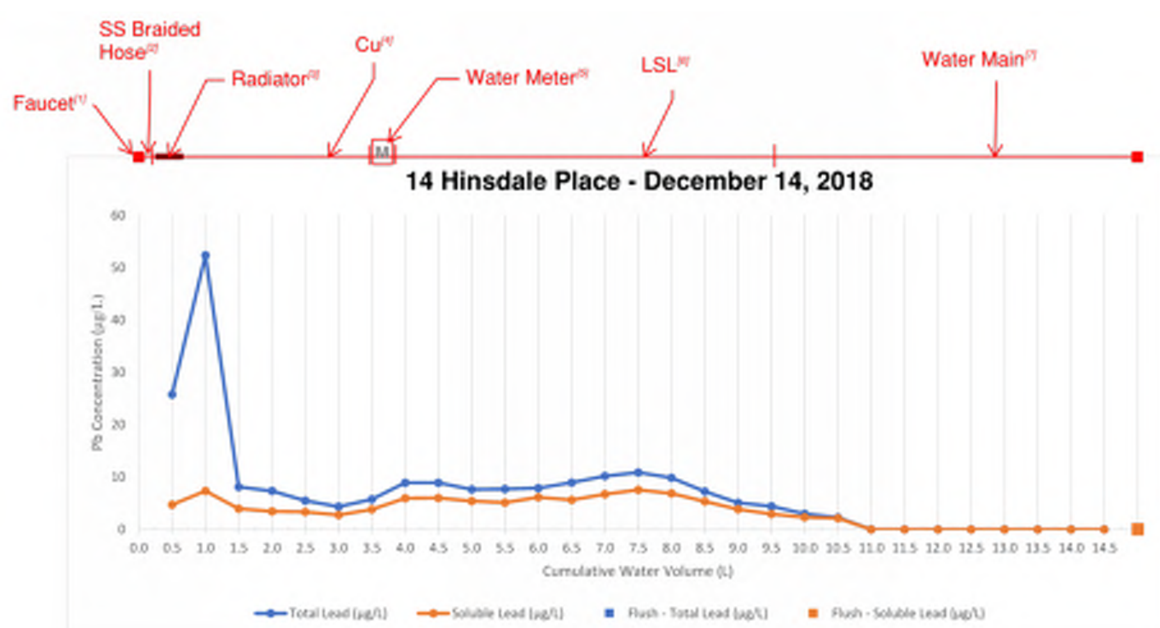
[1] *Values believed to be anomalous, see discussion section.*

Table 4-4 – 14 Hinsdale Place Lead Results

	Before LSLR (12/14/2018)		After LSLR (01/19/2019)	
Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)	Total Lead (µg/L)	Soluble Lead (µg/L)
1	25.8	4.72	13.1	2.78
2	52.4	7.35	9.11	3.23
3	8.11	3.95	5.18	< 2.0
4	7.34	3.44	17.0	< 2.0
5	5.49	3.34	5.6	< 2.0
6	4.37	2.75	5.64	2.23
7	5.75	3.83	6.39	2.67
8	8.91	5.96	4.61	< 2.0
9	8.91	5.99	2.38	< 2.0
10	7.65	5.44	< 2.0	< 2.0
11	7.73	5.13	< 2.0	< 2.0
12	7.9	6.16	< 2.0	< 2.0
13	8.97	5.66	< 2.0	< 2.0
14	10.2	6.73	< 2.0	< 2.0
15	10.9	7.56	< 2.0	< 2.0
16	9.88	6.87	2.69	< 2.0
17	7.23	5.36	< 2.0	< 2.0
18	5.08	3.87	< 2.0	< 2.0

	Before LSLR (12/14/2018)		After LSLR (01/19/2019)	
Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)	Total Lead (µg/L)	Soluble Lead (µg/L)
19	4.43	2.96	< 2.0	< 2.0
20	3.00	2.34	< 2.0	< 2.0
21	2.3	2.15	< 2.0	7.68[1]
22	2.04	< 2.0	< 2.0	< 2.0
23	< 2.0	< 2.0	< 2.0	< 2.0
24	< 2.0	< 2.0	< 2.0	7.44[1]
25	< 2.0	< 2.0	< 2.0	< 2.0
26	< 2.0	< 2.0	< 2.0	< 2.0
27	< 2.0	< 2.0	< 2.0	< 2.0
28	< 2.0	< 2.0	< 2.0	< 2.0
29	< 2.0	< 2.0	< 2.0	< 2.0
FLUSH	< 2.0	< 2.0	< 2.0	14.4[1]

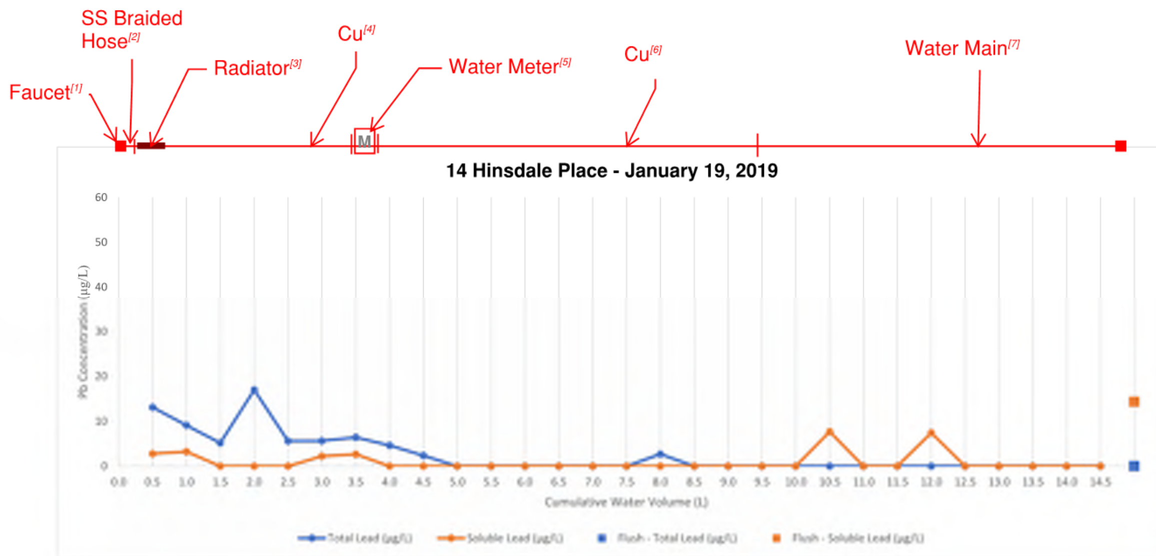
[1] Original testing of samples resulted in soluble lead greater than total lead which is not plausible.



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Approximate Radiator Location Under Copper Pipe Segment, [4] Copper Pipe Segment, [5] Water Meter Location, [6] Lead Service Line Pipe Segment, [7] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-4 – 14 Hinsdale Place Lead Profile – December 14, 2018



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Approximate Radiator Location Under Copper Pipe Segment, [4] Copper Pipe Segment, [5] Water Meter Location, [6] New Copper Service Line Pipe Segment, [7] Water Main Location
Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-5 – 14 Hinsdale Place Lead Profile – January 19, 2019

- Silica concentrations were an average of 6.45 mg/L as SiO_2 for the first sequential sampling, which does not coincide with the Wanaque WQPs measured at the Belleville Reservoir, but rather with the average WQPs for the Pequannock service area. The silica concentration was not tested during the second sequential sampling event .
- All orthophosphate results were less than 0.3 mg/L as PO_4 for the first sequential sampling. For the second sequential sampling event, the orthophosphate results were less than 0.3 mg/L as PO_4 in the internal plumbing samples and the orthophosphate level was 2.11 mg/L as PO_4 in the flushed sample. The interior plumbing orthophosphate results and the flushed sample in the first sequential sampling event do not coincide with the Wanaque WQPs measured in the distribution system indicating potential intermittent supplementation by the Pequannock water. Newark performed additional sampling at a hydrant on Hinsdale Place on January 30, 2019 which resulted in an orthophosphate level of 0.75 mg/L as PO_4. Note that the orthophosphate analysis was performed "out of hold," or after the 48 hour required analysis time for a sample in the first sequential sampling event.
- Based on the water quality data collected at the tap, this location appears to have been influenced by the Pequannock Gradient water at the time of the sampling events.
- The total copper results for the first sequential sampling ranged from ND to the maximum value of 0.296 mg/L (2nd sample). For the second sequential sampling, the total copper results ranged from 0.11 mg/L to the maximum value of 1.65 mg/L (10th sample).

- The pH measurements averaged 6.82, which is lower than the Wanaque WQPs measured in the distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. As mentioned above in the discussion in Section 4.2.1 regarding pH probes, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.

- The flow rate was measured on site during the sampling. The first sampling event occurred using a flow rate of 0.64 gpm and the second sequential sampling had a flow rate of 1.60 gpm.

- The pH, temperature and chlorine residual were unable to be tested on site for the first sequential sampling. However, the temperature of the first 9 samples was fairly warm. During the site audit, a radiator was found to be located directly underneath a portion of the copper line in the basement. The radiator appears to be the source of the temperature increase and may have an impact on soluble and insoluble lead levels as warmer water increases lead levels in drinking water.

- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead results were ND in the first sequential sampling. After the service line was replaced, the soluble lead concentration was 14.1 µg/L and the total lead was ND in the flushed sample. The samples where the soluble lead is greater than the total lead are not plausible and are considered erroneous.

4.2.3 East Ward – 26 ½ Gotthardt Street

It was estimated that 26 ½ Gotthardt Street needed thirteen (13) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and lead solder with copper indoor plumbing before the meter. The following are the observations for the lead profile results for 26 ½ Gotthard Street, as shown in **Tables 4-5** and **4-6** and **Figure 4-6.** It should be noted that some samples were re-tested for quality assurance. Both sample results, when applicable, are provided in **Table 4-6**.

Table 4-5 – Water Quality Analysis at 26 ½ Gotthardt Street

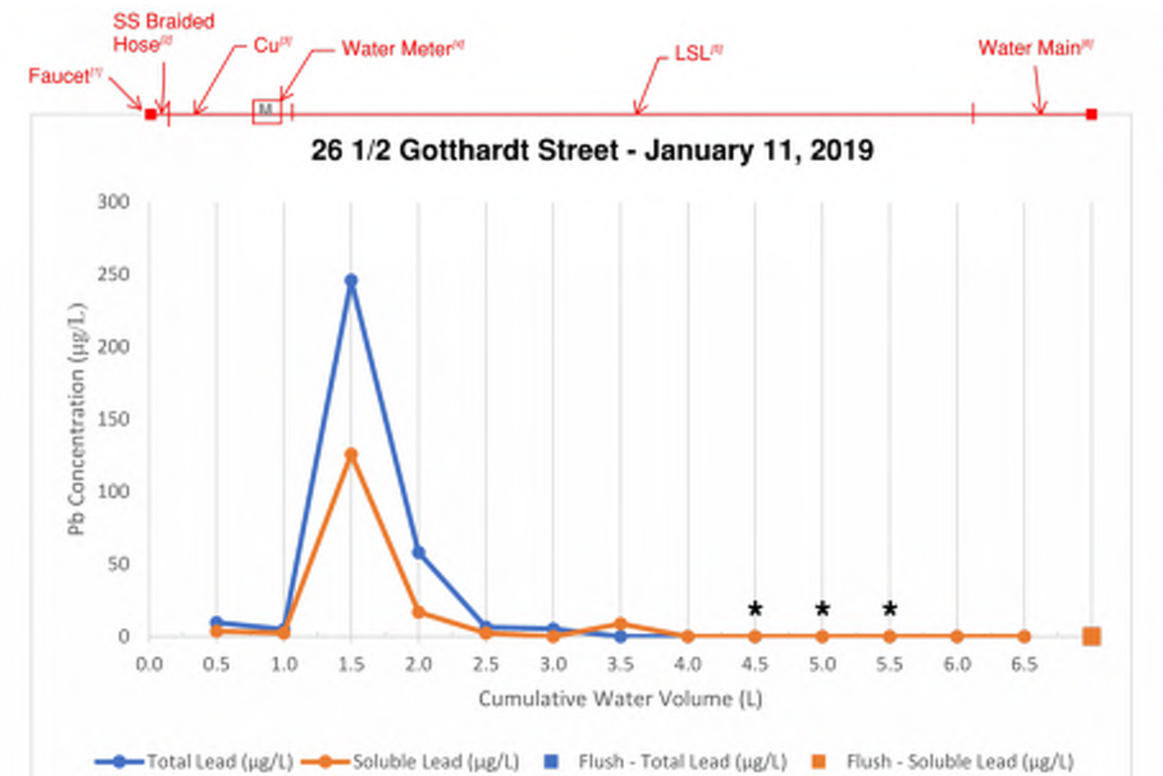
Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
First Liter	6.50	16.1	0.10	31.0	242.0	3.55	0.741 (2.22 mg/L as PO_4)
Middle Samples	6.48	16.6	0.29	30.0	239.0	3.73	0.800 (2.40 mg/L as PO_4)
Flushed Sample	6.62	16.0	0.62	30.0	241.0	3.64	0.749 (2.25 mg/L as PO_4)

[1] *Values believed to be anomalous, see discussion section.*

Table 4-6 – 26 ½ Gotthardt Street Lead Results

Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)
1	9.72	3.86
2	4.95	2.52
3	246	126
4	58.2	17
5	6.56	2.5
6	5.28	< 2.0
7	< 2.0	8.88[2]
8	< 2.0	< 2.0
9	< 2.0	< 2.0
10	< 2.0	< 2.0 (261)[1]
11	< 2.0	< 2.0 (4.03)[1]
12	< 2.0	< 2.0 (2.38)[1]
13	< 2.0	< 2.0
Flushed	< 2.0	< 2.0

[1] Original testing of samples in parentheses (X) resulted in soluble lead greater than total lead which is not plausible. Samples retested.
[2] Original testing of samples resulted in soluble lead greater than total lead which is not plausible.



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Copper Pipe Segment, [4] Water Meter Location, [5] Lead Service Line Pipe Segment, [6] Water Main Location

**Result shown was from re-tested sample. Original result indicated soluble lead greater than total lead which is not plausible. Both results are provided in the table.*

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-6 – 26 ½ Gotthardt Street Lead Profile – January 11, 2019

- The highest lead levels at this address were found in the interior plumbing components, including the faucet hosing and piping connected to the faucet. The aerator was connected to the faucet fixture and was unable to be removed for flushing and sampling. Soluble lead originally peaked at 261 µg/L in the 10th sample (which was shown to be greater than total lead), but after re-testing the sample it was determined to be ND. The updated results determined that the soluble lead peaked at 126 µg/L and total lead peaked at 246 µg/L in the third sample, which represents the copper piping before the meter through a portion of the lead service line and includes the water meter and brass fittings. The samples where the soluble lead is greater than the total lead are not plausible and are considered to be erroneous.
- Elevated particulate lead was found at this address in the third sample.
- Silica concentrations were an average of 3.64 mg/L as SiO_2, which coincides with the Wanaque WQP ranges.
- Orthophosphate measurements were an average of 2.29 mg/L as PO_4, which coincides with the Wanaque WQP ranges.
- Based on the water quality data collected at the tap, this location does not appear to have been influenced by the Pequannock Gradient water at the time of sampling event.
- The total copper results ranged from ND to the maximum value of 0.224 mg/L (found in the 3rd sample).
- The pH measurements were an average of 6.53, which is lower than the WQPs measured in the Wanaque distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. As mentioned above in the discussion in Section 4.2.1 regarding pH probes, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.
- The flow rate was measured on site during the sampling and the samples were collected at a flow rate of 1.28 gpm.
- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead concentrations were ND in the flushed sample.

4.2.4 East Ward – 285 Chestnut Street

It was estimated that 285 Chestnut Street needed ten (10) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and there was no lead solder found on the copper indoor plumbing before the meter. A portion of the lead service line was sent to the EPA for a cross section scale analysis following the sequential sampling event. The following are the observations for the lead profile results for 285 Chestnut Street, as shown in **Tables 4-7** and **4-8** and **Figure 4-7**.

Table 4-7 – Water Quality Analysis at 285 Chestnut Street

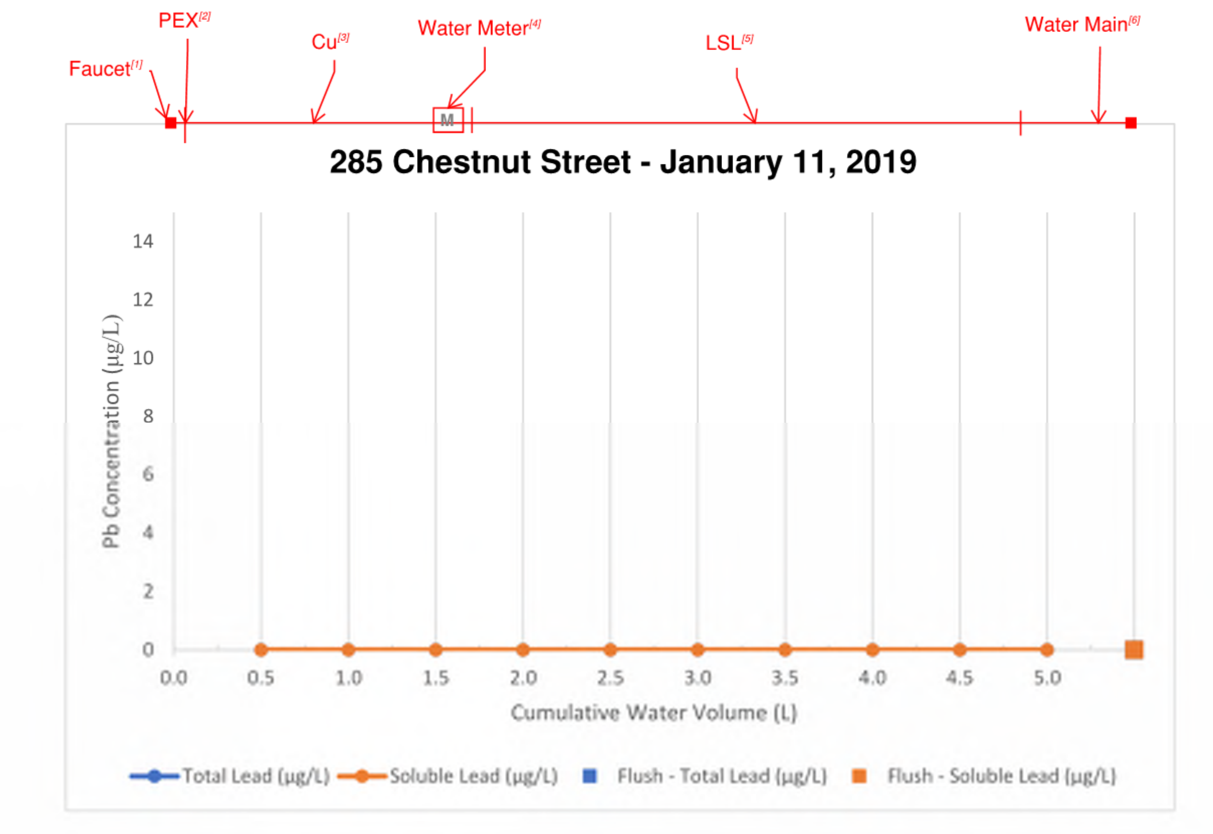
Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
First Liter	6.25	17.4	0.03	32.0	243.0	3.46	0.663 (1.99 mg/L as PO_4)
Middle Samples	6.30	18.0	0.14	32.0	242.0	3.76	0.705 (2.16 mg/L as PO_4)
Flushed Sample	6.36	20.0	0.36	31.0	240.0	3.75	0.700 (2.10 mg/L as PO_4)

[1] Values believed to be anomalous, see discussion section.

Table 4-8 – 285 Chestnut Street Lead Results

Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)
1	< 2.0	< 2.0
2	< 2.0	< 2.0
3	< 2.0	< 2.0
4	< 2.0	< 2.0
5	< 2.0	< 2.0
6	< 2.0	< 2.0
7	< 2.0	< 2.0
8	< 2.0	< 2.0
9	< 2.0	< 2.0
10	< 2.0	< 2.0
Flushed	< 2.0	< 2.0

- There was no lead detected in any of the samples at this address.
- The aerator was connected to the faucet fixture and was unable to be removed for flushing and sampling.
- Silica concentrations were an average of 3.70 mg/L as SiO_2, which coincides with the Wanaque WQP ranges.
- Orthophosphate measurements were an average of 2.08 mg/L as PO_4, which coincides with the Wanaque WQP ranges.
- Based on the water quality data collected at the tap, this location does not appear to have been influenced by the Pequannock Gradient water at the time of the sampling event.
- The total copper results were ND for all samples.



[1] Kitchen Faucet Location, [2] Cross-Linked Polyethylene Pipe Segment, [3] Copper Pipe Segment, [4] Water Meter Location, [5] Lead Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-7 – 285 Chestnut Street Lead Profile – January 11, 2019

- The pH measurements were an average of 6.30, which is lower than the Wanaque WQPs measured in the distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. As mentioned above in the discussion in Section 4.2.1 regarding pH probes, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.
- The flow rate was measure on site during the sampling and the samples were collected at a flow rate of 0.98 gpm.
- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead concentrations were ND in the flushed sample.

4.2.5 East Ward – 64 Garrison Street

It was estimated that 64 Garrison Street needed twenty (20) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and lead solder with copper indoor plumbing before the meter. The following are the observations for the lead profile results for 64 Garrison Street, as shown in **Tables 4-9** and **4-10** and **Figure 4-8.** It should be noted that some samples were re-tested by the laboratory for quality assurance. Both sample results, when applicable, are provided in **Table 4-10**.

Table 4-9 – Water Quality Analysis at 64 Garrison Street

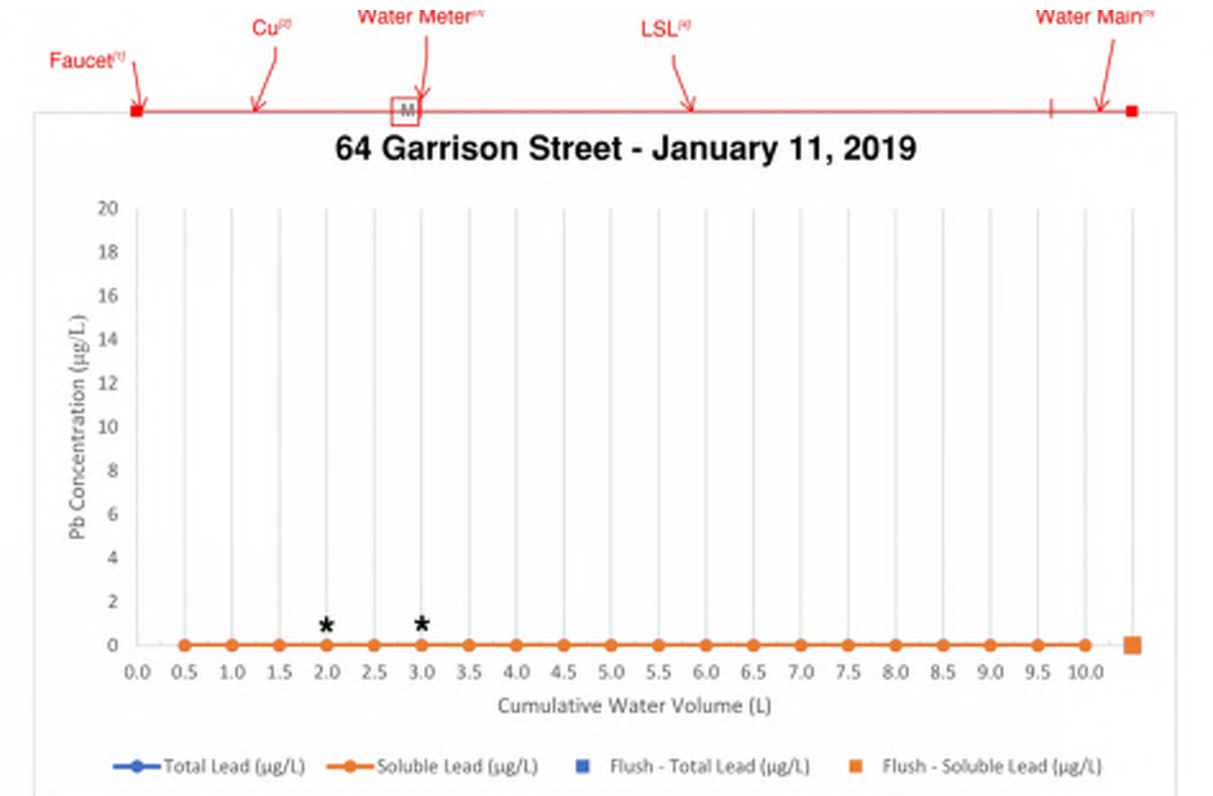
Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
First Liter	6.53	19.1	0.21	30.0	242.0	3.90	0.710 (2.13 mg/L as PO_4)
Middle Samples	6.31	18.8	0.35	30.0	238.0	3.80	0.714 (2.14 mg/L as PO_4)
Flushed Sample	6.30	18.2	0.53	30.0	233.0	3.72	0.715 (2.15 mg/L as PO_4)

[1] Values believed to be anomalous, see discussion section.

Table 4-10 – 64 Garrison Street Lead Results

Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)
1	< 2.0	< 2.0
2	< 2.0	< 2.0
3	< 2.0	< 2.0
4	< 2.0 (5.62)[1]	< 2.0 (17.9)[1]
5	< 2.0	< 2.0
6	< 2.0	< 2.0 (4.84)[1]
7	< 2.0	< 2.0
8	< 2.0	< 2.0
9	< 2.0	< 2.0
10	< 2.0	< 2.0
11	< 2.0	< 2.0
12	< 2.0	< 2.0
13	< 2.0	< 2.0
14	< 2.0	< 2.0
15	< 2.0	< 2.0
16	< 2.0	< 2.0
17	< 2.0	< 2.0
18	< 2.0	< 2.0
19	< 2.0	< 2.0
20	< 2.0	< 2.0
Flushed	< 2.0	< 2.0

[1] Original testing of samples in parentheses (X) resulted in soluble lead greater than total lead which is not plausible. Samples retested.



[1] Kitchen Faucet Location, [2] Copper Pipe Segment, [3] Water Meter Location, [4] Lead Service Line Pipe Segment, [5] Water Main Location

**Result shown was from re-tested sample. Original result indicated soluble lead greater than total lead which is not plausible. Both results are provided in the table.*

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-8 – 64 Garrison Street Lead Profile – January 11, 2019

- There was no lead detected in any of the samples at this address. Originally, the highest lead levels at this address were found in the interior plumbing components, including the faucet and piping connected to the faucet. Soluble lead originally peaked at 17.9 µg/L and total lead peaked at 5.62 µg/L in the fourth sample, which represents the copper line in the premise plumbing. It is not possible for soluble lead to be greater than total lead, and as such, the samples were reanalyzed. After re-testing, the amount of lead was found to be ND in all samples.
- The aerator was removed before collecting samples.
- Silica concentrations were an average of 3.80 mg/L as SiO_2, which coincides with the Wanaque WQP ranges.
- Orthophosphate measurements were an average of 2.14 mg/L as PO_4, which coincides with the Wanaque WQP ranges.

- Based on the water quality data collected at the tap, this location does not appear to have been influenced by the Pequannock Gradient water at the time of the sampling event.
- The total copper results were ND for all samples.
- The pH measurements were an average of 6.39, which is lower than the Wanaque WQPs measured in the distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. As mentioned above in the discussion in Section 4.2.1 regarding pH probes, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.
- The flow rate was measure on site during the times of sampling and the samples were collected at a flow rate of 0.74 gpm.
- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead concentrations were ND in the flushed sample.

4.2.6 East Ward – 63 ½ Garrison Street

It was estimated that 63 ½ Garrison Street needed seventeen (17) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and lead solder with copper indoor plumbing before the meter. The following are the observations for the lead profile results for 63 ½ Garrison Street, as shown in **Tables 4-11** and **4-12** and **Figure 4-9**.

- The total lead peaked at 3.97 µg/L in the first sample, which represents the interior plumbing components, including the faucet hosing and piping connected to the faucet. There was no soluble lead detected in any of the samples at this address. The aerator was removed on site before collecting samples.
- There was a slight amount of particulate lead found in the sixth and seventh samples. These samples represent the lead service line located before the curb box.
- Silica concentrations were an average of 3.55 mg/L as SiO_2, which coincides with the Wanaque WQP ranges.
- Orthophosphate measurements were an average of 2.15 mg/L as PO_4, which coincides with the Wanaque WQP ranges.
- Based on the water quality data collected at the tap, this location does not appear to have been influenced by the Pequannock Gradient water at the time of the sampling events.
- The total copper results ranged from ND to the maximum value of 0.0501 mg/L (first sample).

Table 4-11 – Water Quality Analysis at 63 ½ Garrison St.

Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
First Liter	6.62	20.3	0.16	36.0	234.0	3.86	0.708 (2.12 mg/L as PO_4)
Middle Samples	6.56	18.5	0.65	32.0	232.0	3.63	0.718 (2.15 mg/L as PO_4)
Flushed Sample	6.61	15.7	0.69	29.0	210.0	3.15	0.728 (2.18 mg/L as PO_4)

[1] Values believed to be anomalous, see discussion section.

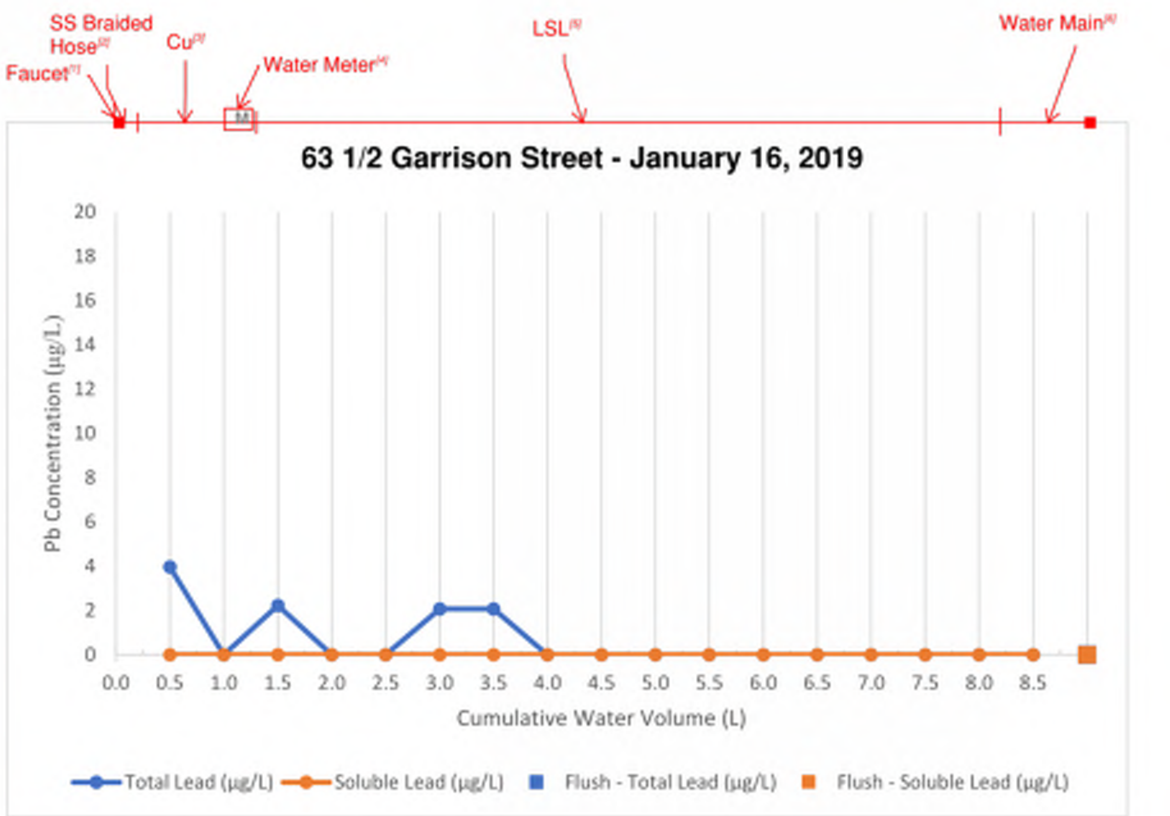
Table 4-12 – 63 ½ Garrison St. Lead Results

Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)
1	3.97	< 2.0
2	< 2.0	< 2.0
3	2.23	< 2.0
4	< 2.0	< 2.0
5	< 2.0	< 2.0
6	2.07	< 2.0
7	2.07	< 2.0
8	< 2.0	< 2.0
9	< 2.0	< 2.0
10	< 2.0	< 2.0
11	< 2.0	< 2.0
12	< 2.0	< 2. 0
13	< 2.0	< 2.0
14	< 2.0	< 2.0
15	< 2.0	< 2.0
16	< 2.0	< 2.0
17	< 2.0	< 2.0
Flushed	< 2.0	< 2.0

- The pH measurements were an average of 6.60, which is lower than the Wanaque WQPs measured in the distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. As mentioned above in the discussion in Section 4.2.1 regarding pH probes, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.

- The flow rate was measured on site during the sampling and the samples were collected at a flow rate of 1.84 gpm.

- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead concentrations were ND in the flushed sample.



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Copper Pipe Segment, [4] Water Meter Location, [5] Lead Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-9 – 63 ½ Garrison St. Lead Profile – January 16, 2019

4.2.7 North Ward – 16 Hinsdale Place

It was estimated that 16 Hinsdale Place needed seventeen (17) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main. This home had a lead service line and lead solder on the copper indoor plumbing before the meter. A portion of the lead service line was sent to the EPA for a cross section scale analysis following the sequential sampling event. The following are the observations for the lead profile results for 16 Hinsdale Place, as shown in **Tables 4-13** and **4-14** and **Figure 4-9**.

- The soluble lead at this address peaked at 5.31 µg/L and total lead peaked at 7.6 µg/L in the 7th sample, which represents where the copper piping transitions to the LSL and includes the meter and brass fittings.

- The aerator was connected to the faucet fixture and was unable to be removed for flushing and sampling.

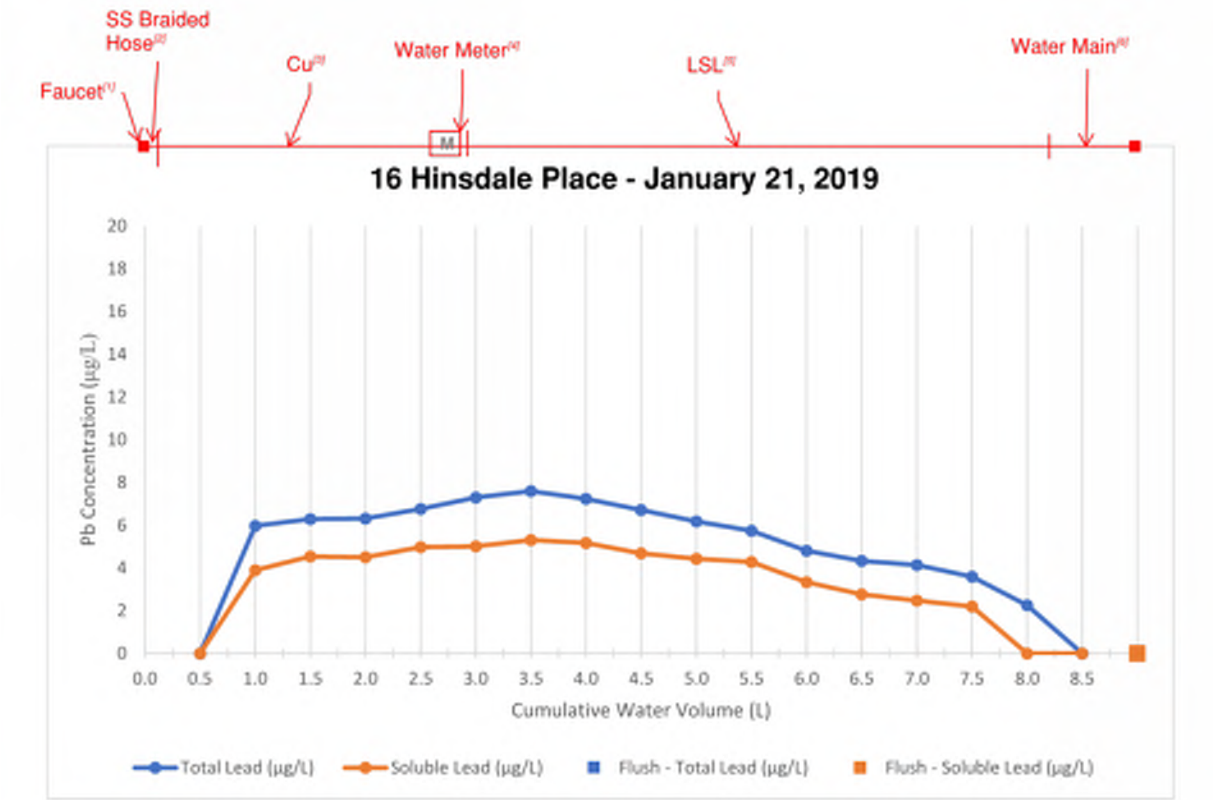
Table 4-13 – Water Quality Analysis at 16 Hinsdale Place

Sample ID	pH[1]	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Conductivity (uMhos/cm)	Silica (mg/L SiO_2)	Orthophosphate (as P)
First Liter	6.60	13.2	0.19	29.0	197.0	N/A	< 0.1 (< 0.3 mg/L as PO_4)
Middle Samples	6.62	11.1	0.62	27.0	201.0		< 0.1 (< 0.3 mg/L as PO_4)
Flushed Sample	6.63	9.18	0.67	28.0	203.0		0.768 (2.30 mg/L as PO_4)

[1] Values believed to be anomalous, see discussion section.

Table 4-14 – 16 Hinsdale Place Lead Results

Sample ID	Total Lead (µg/L)	Soluble Lead (µg/L)
1	< 2.0	< 2.0
2	5.97	3.9
3	6.29	4.54
4	6.32	4.51
5	6.76	4.98
6	7.3	5.01
7	7.6	5.31
8	7.24	5.17
9	6.71	4.69
10	6.18	4.43
11	5.74	4.28
12	4.81	3.34
13	4.33	2.77
14	4.14	2.48
15	3.59	2.2
16	2.26	< 2.0
17	< 2.0	< 2.0
Flushed	< 2.0	< 2.0



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Copper Pipe Segment, [4] Water Meter Location, [5] Lead Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-10 – 16 Hinsdale Pl. Lead Profile – January 21, 2019

- The orthophosphate measurements of the samples representing the interior plumbing were both less than 0.3 mg/L as PO_4, which does not coincide with the Wanaque WQPs measured in the distribution system and indicates potential supplementation by the Pequannock water. However, the flushed sample of orthophosphate resulted in a value of 2.30 mg/L as PO_4 which coincides with the Wanaque WQPs measured in the distribution system. Newark performed additional sampling at a hydrant on Hinsdale Place on January 30, 2019 which resulted in an orthophosphate level of 0.75 mg/L as PO_4.

- Based on the water quality data collected at the tap, this location appears to have been influenced by the Pequannock Gradient water at the time of the sampling events based on the orthophosphate sample results. With significantly higher orthophosphate residual in the flushed samples than the stagnated samples on Hinsdale Avenue, it is possible that the scales in this area currently have an orthophosphate demand.

- The total copper results ranged from 0.0161 mg/L up to the maximum value of 0.222 mg/L (first sample).

- The pH measurements were an average of 6.62, which is lower than the Wanaque WQPs measured in the distribution system. pH readings were collected in the field and are significantly lower than what would be expected based on WQP sampling as well as routine monitoring of the POE pH by the NJDWSC. As mentioned above in the discussion in Section 4.2.1 regarding pH probes, it is suspected that the low pH readings found during the sequential sampling are not representative of actual conditions.

- The flow rate was measured on site during the times of sampling and occurred using a flow rate of 0.78 gpm.
- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead resulted as ND in the flushed sample.

4.2.8 South Ward – 85 Astor Street (Previously East Ward)

The address 85 Astor Street is located in the South Ward. The mapping in **Figure 4-1** shows the address in the East Ward based on the previous ward boundaries. It was estimated that 85 Astor Street needed (9) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main, in addition to collecting eight (8) 125 mL bottles to represent the first liter. This home had a lead service line and lead solder with copper and a segment of galvanized steel indoor plumbing. A portion of the lead service line was sent to the EPA for a scale analysis following the sequential sampling event. The following are the observations for the lead profile and water quality results for 85 Astor Street, as shown in **Tables 4-15**, **4-16** and **4-17**, and **Figure 4-11**. It should be noted that laboratory analyses not performed in the field was performed by the EPA Region 2 laboratory for this site.

Table 4-15 – Water Quality Analysis at 85 Astor Street

Sample ID	pH	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Silica (mg/L SiO_2)	Orthophosphate (as P)
Second Liter	7.80	13.8	0.93	27.20	N/A	0.52 (1.56 mg/L as PO_4)
Flushed Samples	7.78	13.6	0.89	24.60	N/A	0.52 (1.56 mg/L as PO_4)

Table 4-16 – 85 Astor Street Lead Results

Sample ID	Total Lead (µg/L)
1	ND
2	ND
3	ND
4	ND
5	1.04
6	1.04
7	1.03
8	1.13
9	1.12
10	1.08

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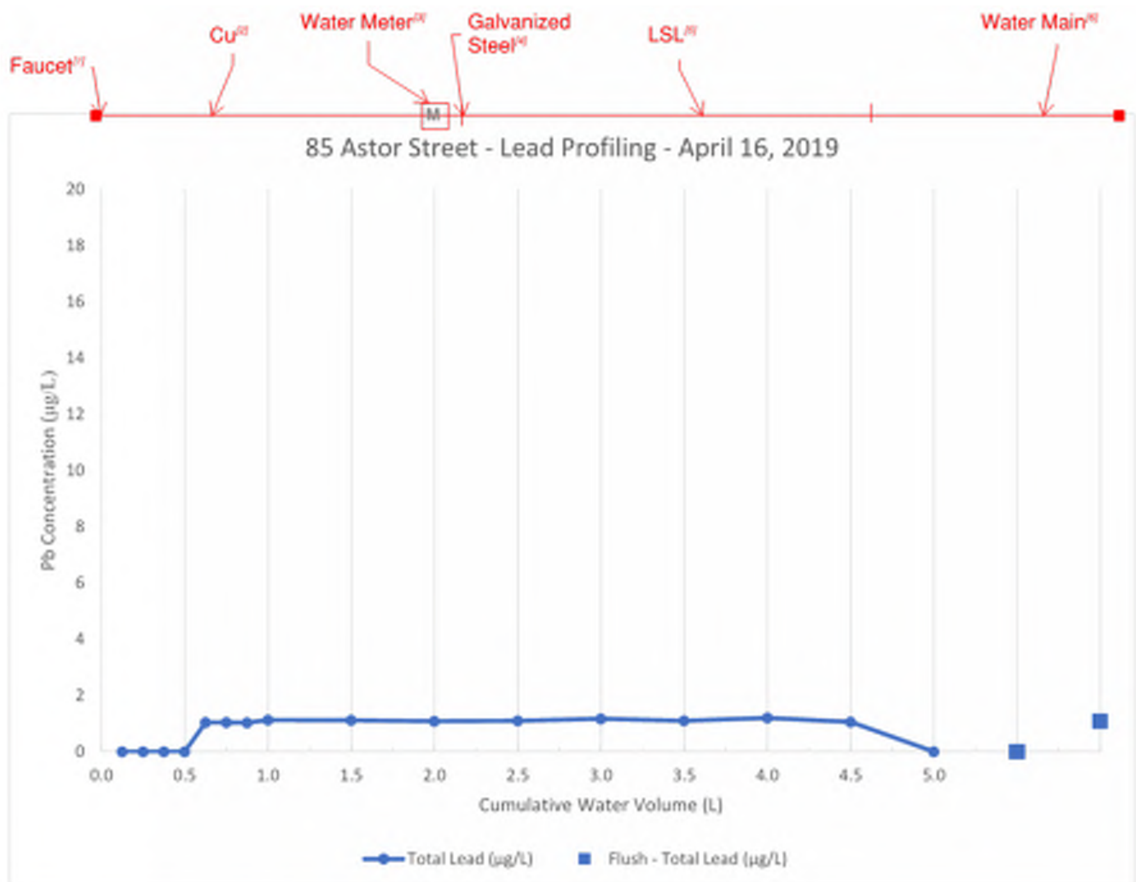
Sample ID	Total Lead (µg/L)
11	1.10
12	1.17
13	1.10
14	1.20
15	1.06
16	ND
Flushed	ND
Flushed	1.08

Table 4-17 – Flushed Water Quality Analysis at 85 Astor Street

Analyte	Result
Calcium (µg/L)	10700
Iron (µg/L)	0
Magnesium (µg/L)	2850
Potassium (µg/L)	818
Sodium (µg/L)	24500
Aluminum (µg/L)	45.1
Antimony (µg/L)	0
Arsenic (µg/L)	0
Barium (µg/L)	7.06
Beryllium (µg/L)	0
Cadmium (µg/L)	0
Chromium (µg/L)	0
Cobalt (µg/L)	0
Manganese (µg/L)	3.89
Molybdenum (µg/L)	0
Nickel (µg/L)	0
Selenium (µg/L)	0
Silver (µg/L)	0
Thallium (µg/L)	0
Vanadium (µg/L)	0
Zinc (µg/L)	2.81
Chloride (mg/L)	48
Fluoride (mg/L)	0
Sulfate (mg/L)	6.8



[1] Kitchen Faucet Location, [2] Copper Pipe Segment, [3] Water Meter Location, [4] Galvanized Steel Pipe Segment, [5] Lead Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-11 – 85 Astor Street Lead Profile – April 16, 2019

- The total lead at this address peaked at 1.20 µg/L in the 14th sample, which represents the lead service line piping right before the water main.
- The aerator was removed prior to sample collection.
- The silica concentrations are unavailable for this site.
- The orthophosphate measurement in the flushed sample was 1.56 mg/L as PO_4, which coincides with the Wanaque WQPs measured in the distribution system.
- Based on the water quality data collected, this location does not appear to have been influenced by the Pequannock Gradient water at the time of the sampling events, based on the orthophosphate results.
- The total copper results ranged from 1.67 mg/L up to the maximum value of 19.9 mg/L (first sample).

- The pH measurements were an average of 7.79, which is within the range of the Wanaque WQPs measured in the distribution system. pH readings were performed in the field.
- The flow rate was measured on site during the time of sampling and occurred using a flow rate of 0.91 gpm.
- After flushing the water at the faucet for 10 minutes, the total lead resulted as ND and 1.08 in the flushed samples.

4.2.9 South Ward – 12-14 Hanford Street

It was estimated that 12-14 Hanford Street needed nine (22) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main, in addition to collecting eight (8) 125 mL bottles to represent the first liter. This home had a lead service line and lead solder with copper indoor plumbing. The following are the observations for the lead profile and water quality results for 12-14 Hanford Street, as shown in **Tables 4-18**, **4-19** and **4-20**, and **Figure 4-12**. It should be noted that laboratory analyses not performed in the field were performed by the EPA Region 2 laboratory for this site.

Table 4-18 – Water Quality Analysis at 12-14 Hanford Street

Sample ID	pH	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Silica (mg/L SiO_2)	Orthophosphate (as P)
Second Liter	7.94	19.0	0.44	26.6	N/A	0.615 (1.85 mg/L as PO_4)
Flushed Samples	7.89	16.2	0.49	25.6	N/A	0.58 (1.75 mg/L as PO_4)

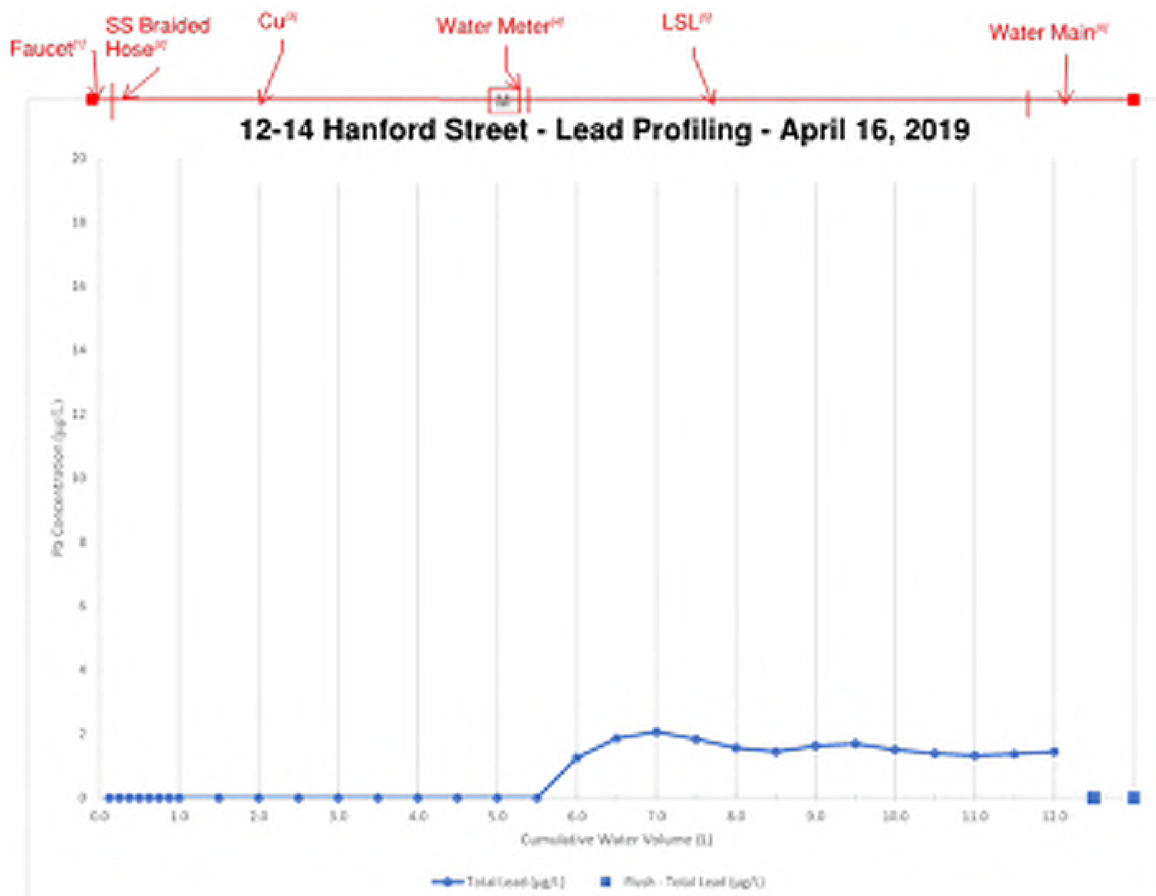
Table 4-19 – 12-14 Hanford Street Lead Results

Sample ID	Total Lead (µg/L)
1	ND
2	ND
3	ND
4	ND
5	ND
6	ND
7	ND
8	ND
9	ND
10	ND
11	ND
12	ND
13	ND
14	ND

Sample ID	Total Lead (µg/L)
15	ND
16	ND
17	ND
18	1.25
19	1.86
20	2.06
21	1.83
22	1.56
23	1.44
24	1.62
25	1.69
26	1.5
27	1.39
28	1.32
29	1.37
30	1.44
Flushed	ND
Flushed	ND

Table 4-20 – Flushed Water Quality Analysis at 12-14 Hanford Street

Analyte	Result
Calcium (µg/L)	10900
Iron (µg/L)	60.50
Magnesium (µg/L)	2880
Potassium (µg/L)	817
Sodium (µg/L)	24600
Aluminum (µg/L)	36.0
Barium (µg/L)	6.81
Manganese (µg/L)	3.13
Chloride (mg/L)	48.0
Fluoride (mg/L)	0.00
Sulfate (mg/L)	7.00



[1] Kitchen Faucet Location, [2] Stainless Steel Braided Hose, [3] Copper Pipe Segment, [4] Water Meter Location, [5] Lead Service Line Pipe Segment, [6] Water Main Location

Note: Lead levels below 2.0 µg/L are below the detection limit and are shown as 0 µg/L for graphical purposes.

Figure 4-12 – 12-14 Hanford Street Lead Profile – April 16, 2019

- The total lead at this address peaked at 2.06 µg/L in the 14th sample, which represents the lead piping segment located after the water meter.
- The silica concentrations are unavailable for this site.
- The aerator was removed prior to sample collection.
- The orthophosphate measurement in the flushed sample was 1.75 mg/L as PO4, which coincides with the Wanaque WQPs measured in the distribution system.
- Based on the water quality data collected, this location does not appear to have been influenced by the Pequannock Gradient water at the time of the sampling events, based on the orthophosphate results.

- The total copper results ranged from 4.4 mg/L up to the maximum value of 106 mg/L (third 125 mL sample).
- The pH measurements were an average of 7.92, which is within the range of the Wanaque WQPs measured in the distribution system. pH readings were performed in the field.
- The flow rate was measured on site during the time of sampling and occurred using a flow rate of 0.86 gpm.
- After flushing the water at the faucet for 10 minutes, the total lead resulted as ND in the flushed samples.

4.2.10 East Ward – 60 Gotthardt Street

It was estimated that 60 Gotthardt Street needed twelve (12) 500 mL samples to encompass the entire interior plumbing and service line prior to reaching the main, in addition to collecting eight (8) 125 mL bottles to represent the first liter. This home had a lead service line and lead solder with copper and a segment of galvanized steel indoor plumbing. The following are the observations for the lead profile and water quality results for 60 Gotthardt Street, as shown in **Tables 4-21**, **4-22** and **4-21**, and **Figure 4-13**. It should be noted that laboratory analyses not performed in the field were performed by the EPA Region 2 laboratory for this site.

Table 4-21 – Water Quality Analysis at 60 Gotthardt Street

Sample ID	pH	Temp (deg C)	Free Cl_2 (mg/L)	Alkalinity (mg/L $CaCO_3$)	Silica (mg/L SiO_2)	Orthophosphate (as P)
Second Liter	7.8	25.4	0.43	27.20	4.54	0.547 (1.64 mg/L as PO_4)
Flushed Samples	7.91	21.8	0.61	28.60	4.28	0.517 (1.55 mg/L as PO_4)

Table 4-22 – 60 Gotthardt Street Lead Results

Sample ID	Total Lead (µg/L)
Q1	ND
Q2	ND
Q3	ND
Q4	ND
Q5	ND
Q6	ND
Q7	ND
Q8	ND
Q9	ND
Q10	ND
Q11	ND

Sample ID	Total Lead (µg/L)
Q12	ND
Q13	ND
Q14	ND
Q15	ND
Q16	ND
Q17	ND
Q18	ND
Q19	ND
Q20	ND
Q21 FLUSH	ND
Q22 FLUSH	Not Tested

Table 4-23 – Flushed Water Quality Analysis at 60 Gotthardt Street

Analyte	Result
Calcium (µg/L)	11600
Iron (µg/L)	0
Magnesium (µg/L)	2880
Potassium (µg/L)	818
Sodium (µg/L)	25400
Aluminum (µg/L)	31.8
Antimony (µg/L)	0
Arsenic (µg/L)	0
Barium (µg/L)	7.38
Beryllium (µg/L)	0
Cadmium (µg/L)	0
Chromium (µg/L)	0
Manganese (µg/L)	1.04
Nickel (µg/L)	0
Selenium (µg/L)	0
Silver (µg/L)	0
Thallium (µg/L)	0
Vanadium (µg/L)	0
Zinc (µg/L)	2.15
Calcium (µg/L)	11600
Iron (µg/L)	50.0
Chloride (mg/L)	46.0
Fluoride (mg/L)	0.05
Sulfate (mg/L)	6.30

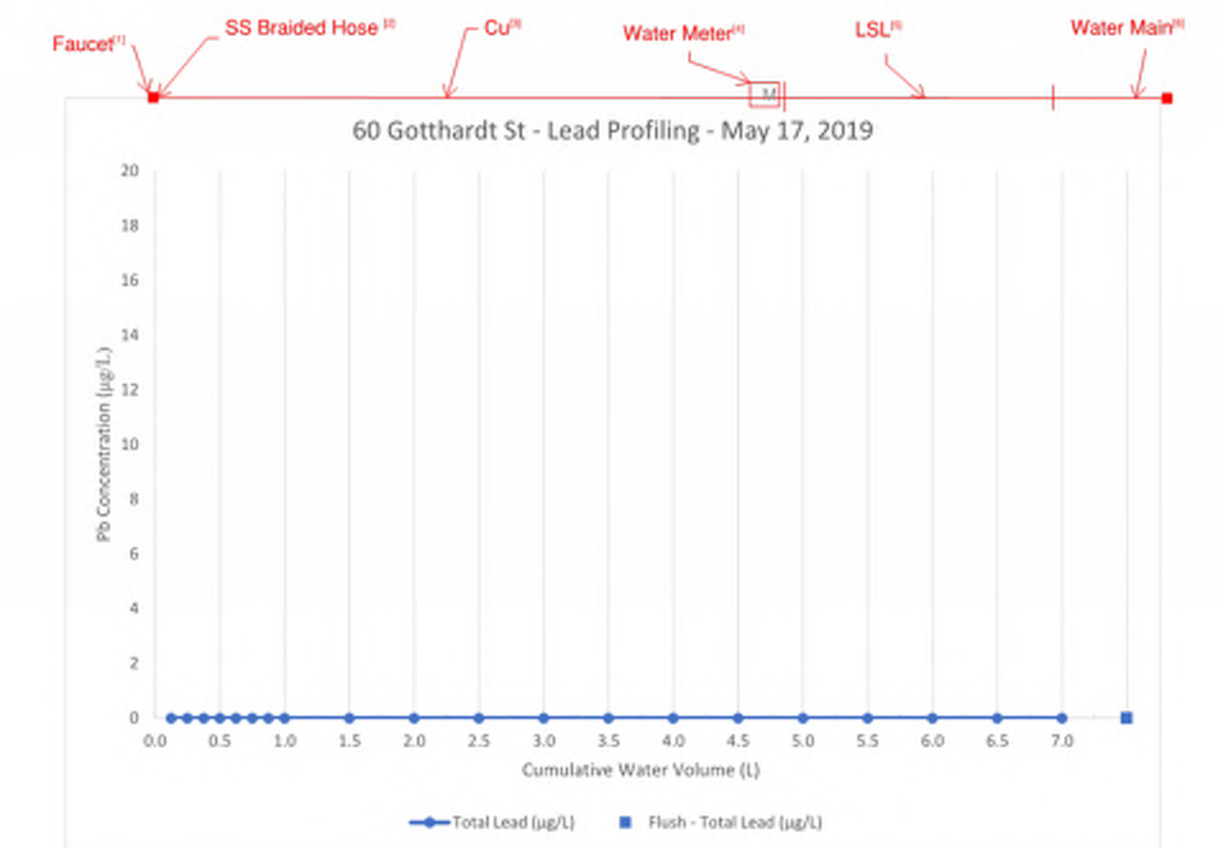


Figure 4-13 – 60 Gotthardt Street Lead Profile – May 17, 2019

- There was no lead detected in any of the samples at this address.
- The aerator was removed before collecting samples.
- Silica concentrations were an average of 4.41 mg/L as SiO_2, which coincides with the Wanaque WQP ranges.
- Orthophosphate measurements were an average of 1.60 mg/L as PO_4, which coincides with the Wanaque WQP ranges.
- Based on the water quality data collected at the tap, this location does not appear to have been influenced by the Pequannock Gradient water at the time of the sampling event.
- The total copper results ranged from 3.85 to the maximum value of 54.8 mg/L (7th sample, located within the first liter).
- The pH measurements were an average of 7.86, which coincides with the Wanaque WQPs measured in the distribution system.

- The flow rate was measured on site during the sampling and the samples were collected at a flow rate of 0.46 gpm.
- After flushing the water at the faucet for 10 minutes, both the soluble lead and total lead concentrations were ND in the flushed samples.

4.3 Discussion

Lead sequential sampling was used in the Wanaque Gradient to compare with the previous sequential sampling performed in the Pequannock Gradient, to isolate the source(s) of lead in tap water in a given home, and to compare soluble and particulate lead as an indication of the stability of the protective scale. In addition, over time, lead sequential sampling can be used as a tool to monitor the effectiveness of CCT implementation or optimization.

It is important to recognize that both site specific and systemic factors may influence the lead levels measured at the water tap. Site specific factors include physical characteristics of the lead service line (length, diameter, surface area), water use patterns before and during sampling, piping configurations, hydraulic conditions, and manufacturing materials used for piping and fittings. Systemic factors include water quality, water pressure, scale formation and scale breakdown on the service line. These factors can contribute to variability in sampling results within the same water system and over time. At 95 Pennsylvania Avenue, 14 Hinsdale Place and 26 ½ Gotthardt Street, higher lead results were found in the interior plumbing or at the start of the lead service line during the sequential sampling. These results are consistent with other sequential sampling studies for systems with orthophosphate treatment that indicate peak lead concentrations often originate from the premise piping and/or the faucet, and not the lead service line where a stable orthophosphate scale may have formed.

4.3.1 Differences Between LCR Compliance Sampling and Sequential Sampling

There are several major differences between LCR compliance sampling (with a Lead AL established at 15 µg/L) and the sequential sampling protocols that may result in the detection of higher lead levels than LCR compliance sampling. Some of the major differences are provided in **Table 4-24**.

Table 4-24 – Key Differences Between LCR Compliance Sampling and Sequential Sampling Protocols

Sampling Characteristic	LCR Compliance Sampling Protocol	Sequential Sampling Protocol	Potential Impact to Lead Results
Sample Volume	First Liter (1,000 mL)	125 mL, 250 mL or 500 mL samples for the first liter and 500 mL samples throughout the remainder of entire service	Smaller volumes collected using the sequential sampling protocol can better identify the location of the source of the lead and can result in a higher value without dilution from a larger sample.

Sampling Characteristic	LCR Compliance Sampling Protocol	Sequential Sampling Protocol	Potential Impact to Lead Results
Stagnation Period	Minimum 6 hours stagnation	6-12 hours of stagnation	A stagnation period greater than 6 hours may increase soluble lead results with changing water quality and water may becoming more aggressive as it stagnates.
Removing the Aerator	Not removed during stagnation or sampling	Removed during sampling (when applicable)	Removing the aerator may increase the reported value of particulate lead because there is no screen to filter the particulates out of the water.
Flushing Before Stagnation Period	No flushing	Flushing before the stagnation period	Flushing before the stagnation period can stimulate migration of particulate lead that has settled throughout the plumbing which may result in higher particulate lead results in sequential sampling.
Sampling Flow Rate	Sampling flow rate should be similar to the flow rate used to fill a glass of water.	Sampling flow rate averaged approximately 1 gpm. This may be slightly higher than the LCR compliance sampling flow rate.	A higher flow rate may disturb settled particulate lead in the home plumbing and show up in the samples.
Sampling Conducted by	Homeowner	Laboratory technician	Sampling protocol procedures are more consistent for multiple sampling sites when one person (i.e. laboratory technician) is taking samples.

Varying lead results are not uncommon when comparing sequential sampling and LCR compliance sampling for systems that are in compliance with the LCR (i.e. 90th percentile of first liter samples below 15 µg/L). As an example, field studies using the sequential sampling method were conducted at drinking water taps in Seattle Public Schools. Results showed elevated lead levels in the first and second samples drawn, which indicated a release of lead likely originating from the water fountain bubbler head or associated fittings and components (Boyd , Pierson, Kirmeyer, Britton, & English, 2006). These sample locations indicated lead results greater than the LCR Lead AL in the sequential sampling testing; however, Seattle has met LCR requirements in their distribution system since 2003.

4.3.2 Samples with Soluble Lead Greater Than Total Load

Soluble lead is tested by filtering out particulate lead from total lead samples. Both soluble lead samples and the total lead samples are acidified prior to testing. The acidification is done in soluble lead samples after the sample is filtered. Soluble lead and particulate lead should theoretically equal total lead.

A few samples in the sequential sampling process were initially reported by the laboratory to have soluble lead greater than total lead. This is clearly inaccurate. Most of the results in Section 4 that indicated soluble lead greater than total lead were retested. The samples that have been retested resulted in soluble lead less than total lead, as expected. Therefore, the samples that were retested were used in the analysis. The original sample values are shown on the tables only for information.

Although lead sampling does have a margin of error, some results indicated significant variations. The laboratory has been requested to provide an explanation for the variability in the results.

4.3.3 Potential Causes of Lead Levels in Premise Plumbing

Lead was a component in solder on copper piping on interior, or premise, plumbing until it was banned in 1986. Brass components also contained significant lead content until 1986 when up to 8-percent of lead (by weight) was allowed to be classified as "lead-free". In 2014, the "lead-free" limit was changed to 0.25-percent by weight by the EPA.

Lead results in premise plumbing after a stagnation period can be greater than lead results in a lead service line when the scale on a lead service line is stable and galvanic reactions between metals (i.e. lead solder and copper piping) or lead in brass fittings dominate the lead profile.

The smaller sampling volume utilized during sequential sampling can provide a better estimate of the source of lead levels in premise plumbing and the contribution of that source to the lead levels detected. Levels of lead that are found in the first few samples taken during sequential sampling may not be representative of the levels of lead seen from the one (1) liter sample required during LCR compliance testing.

The following factors may contribute to elevated levels of lead found in the first two (2) liters of sampling in the Wanaque Gradient samples:

- **Brass components in the premise plumbing or inline service line components.** While plumbing suppliers have now developed fixtures and other plumbing system components that contain no or low levels of lead, many homes in the Wanaque Gradient were constructed prior to 1986 and likely have premise plumbing components that contain brass with lead. Brass materials are known to cause "dezincification". When dezincification occurs, zinc is released from the brass or alloyed material and the remaining lead and copper can react in water by galvanic corrosion, thus allowing further release of lead into the water (Boyd , Pierson, Kirmeyer, Britton, & English, 2006). Brass ferrules, which often contain lead, are often found inside the stainless steel threaded hose connectors that attach the stainless steel braided hose under the sink to the faucet.

- **Faucets and immediate connective piping containing lead.** Faucets and immediate connective piping can provide a significant contribution of lead. The literature reports that faucets and immediate connective piping can contribute 5 to 31 percent of the lead in the first liter sample collected at the tap for LCR compliance testing (Sandvig, et al., 2008). In the case of faucets, variability in configuration and manufacturing can produce variations in lead content. Older faucets or decorative faucets can have higher lead content.

- **Flushing prior to the stagnation period during sequential sampling.** LCR sampling does not require flushing prior to collecting one-liter sample. At sites with lead service lines, fully flushed samples, such as in the sequential sampling, may contain measurable lead due to uptake of particulate lead as the water flows through the system to the tap. Therefore, measurable lead may be present in the background water at the start of the stagnation period for LCR sampling, further elevating lead levels after stagnation (Sandvig, et al., 2008).

- **Particulate lead in the aerator.** Because most of the samples in the sequential sampling were taken with the aerator off, particulate lead that may typically be screened was free to flow into the samples. This can be prevented by regularly cleaning aerators and flushing prior to using the water for drinking or cooking.

- **Inconsistent orthophosphate in the Wanaque Gradient.** It is believed that the zinc orthophosphate from NJDWSC is consistently supplied at an approximately 1.5 to 1.8 mg/L as PO_4 dose. Additional sampling is currently being performed to determine if the orthophosphate has been diluted from the Pequannock water.

- **Wanaque water supplemented by Pequannock water.** As discussed in Section 3.2.1, water from the Pequannock Gradient can enter the Wanaque Gradient through manual division gate valves and through automatic pressure regulating valves. Several areas were identified within the Wanaque Gradient that appear to have experienced diluted orthophosphate residuals and higher silica concentrations, indicating that they were likely influenced by the Pequannock Gradient. Since January 2019, all division gates were closed and orthophosphate levels have increased in the Wanaque Gradient both in the sequential samples and in the WQP samples.

4.3.4 Comparison of Pequannock and Wanaque Sequential Sampling Results

In comparing only the highest lead concentration in the sequential sampling profiles, one would compare the results at some sites in the Wanaque Gradient (95 Pennsylvania Avenue and 26 ½ Gotthardt Street) to the sequential sampling performed in the Pequannock Gradient at 674 5th Street in Newark, which had a peak lead value of 147 μg/L as presented in the Pequannock OCCT report. However, the major difference between the samples taken in the Wanaque Gradient and the samples taken in the Pequannock Gradient is that the Wanaque Gradient profiles consistently result in non-detect lead levels for the majority of the lead service line and for the flushed samples. The profiles performed in the Pequannock Gradient did not result in non-detect lead levels, even in the flushed samples from the water mains that do not contain lead. It was determined in that study that the scales on the lead service lines for those receiving Pequannock water are unstable, and therefore, water passing through the lead service lines is carrying particulate lead from the unstable scales and soluble lead from direct contact with the lead pipes to the tap. This was confirmed through the scale analyses performed by the EPA. As a result, flushing the service line, as generally recommended by the literature in reducing lead levels in drinking water, was deemed ineffective at reducing lead concentrations in the Pequannock Gradient. Based on the sequential sampling alone, it appears that flushing is an effective method in the Wanaque Gradient to reduce lead concentrations at the tap, and the corrosion control treatment provides protection for residents. The nature of the pipe scales is discussed further in Section 5.

Section 5

Scale Analysis

In December 2018 and February, March, and May 2019, Newark sent five (5) lead service pipe segments from where sequential sampling was conducted in December, January, April and May of 2019 to the EPA Advanced Materials and Solids Analysis Research Core in Cincinnati, OH for analysis. The lead service lines were removed from the following selected locations, see Section 4 for reference:

- 95 Pennsylvania Avenue (East Ward)
- 14 Hinsdale Place (North Ward)
- 285 Chestnut Street (East Ward)
- 16 Hinsdale Place (North Ward)
- 85 Astor Street (East Ward)

The locations listed above are shown on the map in **Figure 4-1**. This section presents the results of the analyses that EPA performed on the pipe scales.

Analysis of scales from pipes that reflect actual distribution system conditions provides a direct indication of the effectiveness of a current treatment process to control lead release. Knowledge of the characteristics and behavior of the lead solids that have been formed on the pipe walls can be integrated with water quality and operational information to understand mechanisms of corrosion inhibition, speciation of metals, and predictions of lead mobility/stability, and can assist in implementation of corrective treatment changes. Knowing how a contaminant is chemically associated in distribution system scale materials can help with estimating the probability of unintended adverse consequences of treatment or water quality changes.

5.1 EPA Scale Analysis Testing and Results

The EPA conducted the following tests on the three lead pipes:

- X-ray diffraction (XRD) analysis – identifies crystalline mineral compounds
- Scanning electron microscopy (SEM)/Energy dispersive spectroscopy (EDS) elemental mapping – identifies general areas where different elements exist within the scale

The testing evaluated the scales in different layers on the pipe wall, which can indicate the history of water chemistry impacts over time. The technique involves separating each solid phase layer for analysis, from the outermost layer (the layer in direct contact with the flowing water) to the innermost layer (the layer directly against the lead pipe wall).

The EPA results for 95 Pennsylvania Avenue, 14 Hinsdale Place were provided on February 14, 2018 and on June 19, 2019 for 285 Chestnut Street, 16 Hinsdale Place and 85 Astor Street. .

Figures 5-1 through **5-5** show images of the pipe scales in cross section for each of the three sites. The compilation of the EPA analysis is included as **Appendix A**. A summary of the compounds found at each location from the outermost layer in contact with the flowing water (L1) to the innermost layer adjacent to the pipe wall (highest "L") is provided in **Table 5-1**. The "+" indicates the relative presence of a compound in the scale analyzed.

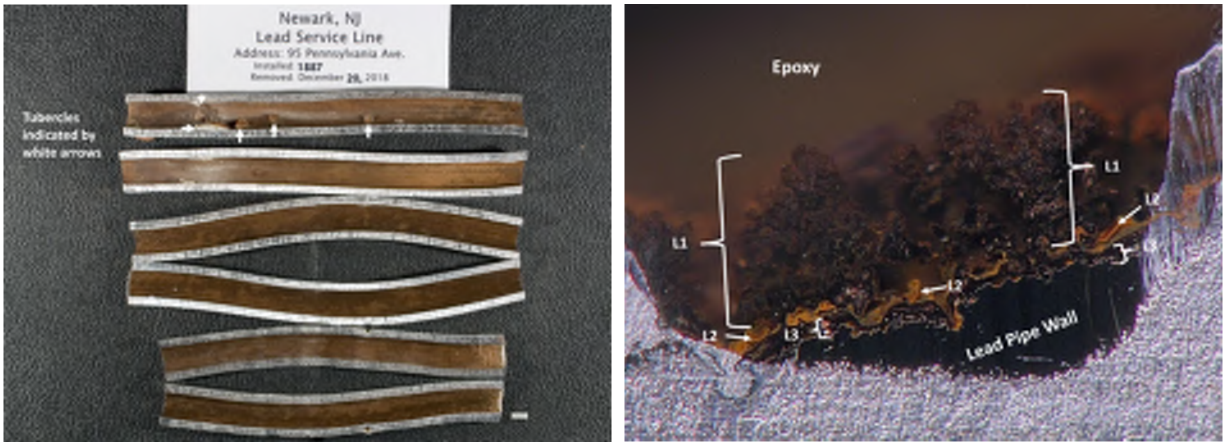


Figure 5-1 – Lead Scale Images for Pipe Extracted from 95 Pennsylvania Avenue

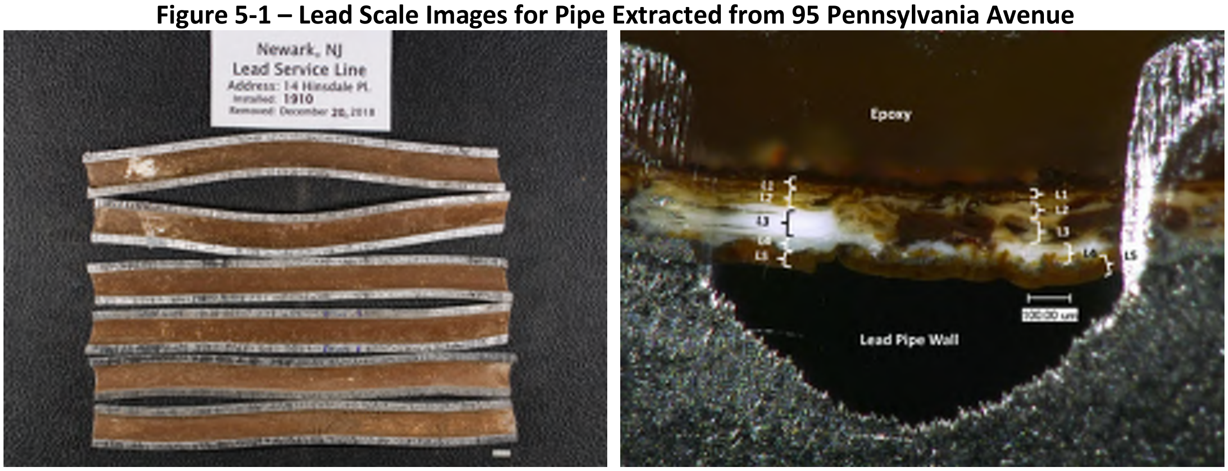


Figure 5-2 – Lead Scale Images for Pipe Extracted from 14 Hinsdale Place

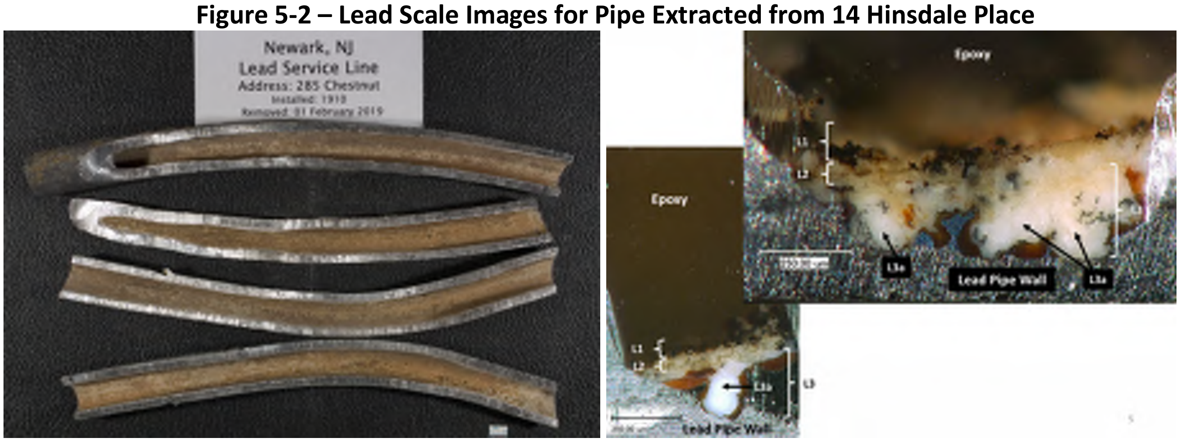


Figure 5-3 – Lead Scale Images for Pipe Extracted from 285 Chestnut Street

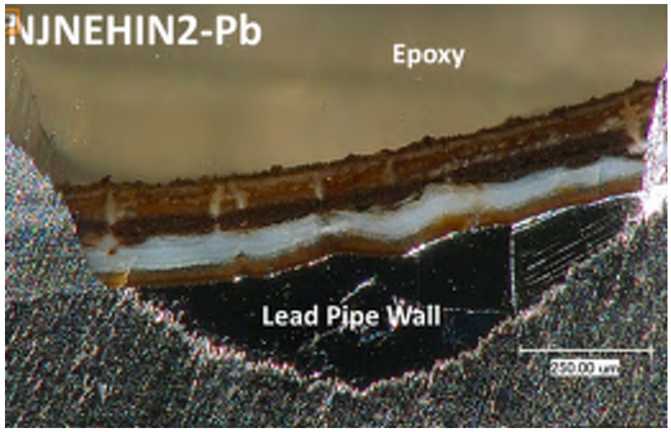


Figure 5-4 – Lead Scale Images for Pipe Extracted from 16 Hinsdale Place

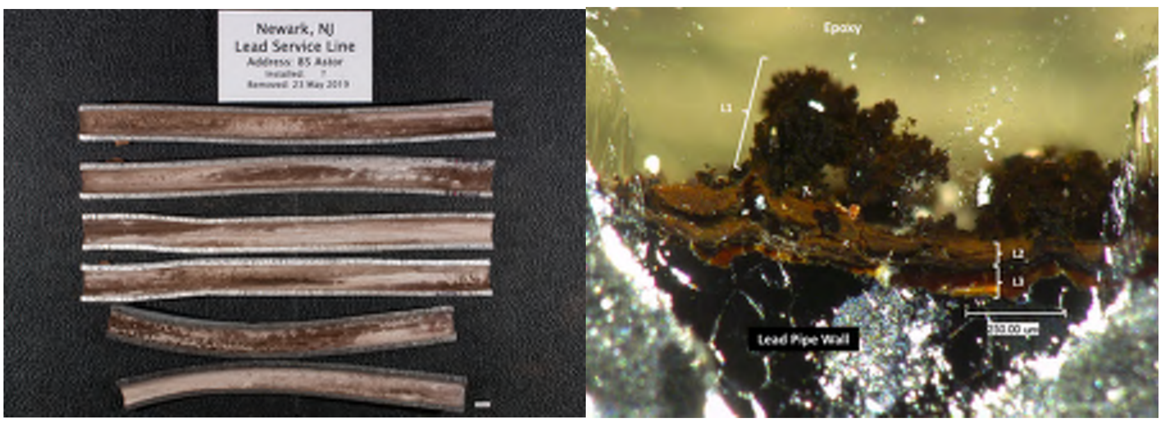


Figure 5-5 – Lead Scale Images for Pipe Extracted from 85 Astor Street

The scales found on the outermost layers were primarily plattnerite for 95 Pennsylvania Avenue and 85 Astor Street and calcium-hydroxypyromorphite with cerrusite for 14 Hinsdale Place and 285 Chestnut Street. Per the cross section analysis, 16 Hinsdale Place did not seem to exhibit a plattnerite texture. The middle portion of the scale seemed to be characterized by the presence of phosphorous.

Plattnerite (PbO_2) is a tetravalent lead (Pb(IV)) compound that is formed over time in waters with high redox potential (ORP). It is reported in the literature that a high ORP can be achieved with free chlorine at levels typically over 1.5 mg/L, and that the rate of formation of PbO_2 appears to increase with increasing pH (Boyd, et al., 2008). Pb(IV) has been observed in systems with free chlorine residuals less than 1.5 mg/L, including Newark. ORP data is not available from within the Newark distribution system so correlations with chlorine residual are not possible. Under these conditions, PbO_2 typically dominates or coexists with Pb(II) mineral forms including hydrocerussite and cerussite. Plattnerite is less soluble than hydrocerussite and cerussite, making plattnerite more effective at achieving low lead levels when the proper (high ORP) water chemistry is maintained.

The pipe scales contain crystalline calcium-hydroxypyromorphite compounds, indicating that the phosphate complexation with lead is currently taking place to control soluble lead levels, as shown in the lead results discussed in Section 4.

Table 5-1 General Characterization of Solid Phases in Pipe Deposits

Location	Layer	Hydrocerussite Pb3(CO3)2(OH2)	Cerrusite Pb(CO3)	Plattnerite PbO2	Ca-hydroxypyromorphite Ca0.805Pb4.195(PO4)3(OH)	Litharge PbO	Laurionite Pb(OH)Cl	Plumbonacrite Pb5O(OH)2(CO3)3	Scrutinyite PbO2
95 Pennsylvania Avenue (East Ward)	L1		+	+++					+
	L2		+	+++					+
	L3		++	+++		++			+
14 Hinsdale Place (North Ward)	L1	+		+	+++				
	L2	+	+	+	+++				
	L3/L4		+++	+++	+++				
	L4	++	+++	+	+	+			
	L5	++	+++		+	+++			
285 Chestnut Street (East Ward)	L1	+	+	+	+++	+			
	L2	+	+	+	+++				
	L3a	++	+++		++	+			
	L3	+	+++		+	+++			
16 Hinsdae Place (North Ward)		No Data							
85 Astor Street (East Ward)	L1	+		+++	+				+
	L2	+		+++		+		+	+
	L3	+	++	++	+	+++			

Note: +++ = predominant, ++ = moderate, and + = trace/minor

5.2 EPA Elemental Analysis Testing and Results

An elemental analysis was also performed via X-ray diffraction (XRD) on the lead services lines discussed in **Section 5.1**. The XRD technology is able to assess the inorganic elemental composition of solid layers on the lead service lines through the solids extraction process. The EPA XRD results (**Appendix A**), provide the concentration of inorganic elements, expressed as micrograms per gram of solid (parts per million) or weight percent (AWWA, 2017).

To put the results below into context, the percentage (by weight) of lead (Pb) in the predominant scale complexes found on the pipes is 77.5% Pb in cerussite ($Pb(CO_3)$), 80.1% Pb in hydrocerussite ($Pb_3(CO_3)_2(OH_2)$), 86.6% Pb in Plattnerite (PbO_2), and 92.8% Pb in Litharge (PbO).

Table 5-2 provides a summary of the elemental data for the most common components found in each layer for the three locations. The sites are discussed individually below. The terminology "inner" refers to the scale layer directly against the lead pipe wall whereas "outer" refers to the scale layer in direct contact with the flowing water. The outermost layer is labeled as L1 and increases numerically, until reaching the innermost layer.

XRD analyses were able to be performed on undisturbed scales, which included only three of the lead pipes: 95 Pennsylvania Avenue, 14 Hinsdale Place and 285 Chestnut Street. The lead pipe from 85 Astor Street was also disturbed, but a small patch of what was believed to be relatively undisturbed scale was analyzed; however, it cannot be confirmed that the scale was undisturbed. Both 14 Hinsdale Place and 85 Astor Street lead pipes were disturbed from excavation. Ccross-sectional images were taken to compare these scales to that from 16 Hinsdale Place and 95 Pennsylvania Avenue, respectively, based on proximity within the distribution system.

The lead scale composition of 14 Hinsdale Place was found to be similar to both 16 Hinsdale Place and 285 Chestnut Street. The scale composition for 85 Astor Street contained minor amounts of calcium-hydroxypyromorphite, which was not found in 95 Pennsylvania Avenue and rather in the scales of 14 Hinsdale Place and 16 Hinsdale Place.

5.2.1 95 Pennsylvania Avenue

The outermost layer had the greatest amount of silica (Si), iron (Fe), aluminum (Al), manganese (Mn), oxygen (O), phosphorous (P), calcium (Ca) which decreased in the subsequent layers. The outermost layer had the lowest amount of lead, which increased significantly toward the innermost layer. The general trend of increasing Pb from the outer to inner layers corresponds to the scale composition consisting of predominantly increasing amounts of PbO_2 to then consisting increasing amounts of PbO and $Pb(CO_3)$ in L3, as presented in **Table 5-1**. The increase in Pb in the layers moving from outer to inner is expected, as the inner layers are closer to the source of lead (the pipe). It should be noted that trench sediment was observed on the scale surface.

On the innermost layer, pockets were found across the length of the pipe and appear to indicate the beginning stages of tubercles observed in the pipe segment. The tubercles were located beneath a layer of plattnerite. The upper and lower layer of the tubercle test results are located in Appendix A. It should also be noted that tin found in the sample may have been from the analysis procedure. The surface texture of layer L3 was rippled and not all of layer L2 could be removed from the surface of layer L3.

Table 5-2 Summary of Scale Composition Elemental Analysis Results

Location	Layer	Elemental* % by Weight										
		Pb	Si	Fe	Al	Mn	O	P	Ca	C [1]	Cl	Sn
95 Pennsylvania Avenue (South Ward)	L1	58.6	1	2.3	1.4	7.4	23.6	1.1	1.2	< 0.5	No data	2.8
	L2	71.3	0.7	1.1	0.8	2.7	18.3	0.7	0.6	< 0.5	No data	3.1
	L3	83.6	No data	< 0.5	< 0.5	0.2	13.7	No data	No data	< 0.5	No data	1.4
14 Hinsdale Place (North Ward)	L1	40.8	8.8	7.5	2.6	1.2	32.1	3.1	1.5	1.01	No data	No data
	L2	62.5	2	3.1	0.9	< 0.5	22.5	4.8	2.5	1.28		
	L3/L4	75.9	No data	< 0.5	< 0.5	< 0.5	16.4	3.2	1.7	1.93		
	L4	80.1		< 0.5	< 0.5	No data	15.4	0.7	< 0.5	2.98		
	L5	85.0		< 0.5	< 0.5		12.9	< 0.5	< 0.5	1.37		
285 Chestnut Street (East Ward)	L1	78.0	1	2.6	0.77	2.6	No data	4.9	3	1.21	1.3	0.5
	L2	82.0	< 0.5	< 0.5	< 0.5	0.54		7.4	4	1.29	2.1	< 0.5
	L3a	88.0	< 0.5	< 0.5	0.61	< 0.5		2.4	1.3	2.39	0.81	No data
	L3	98.0	< 0.5	< 0.5	< 0.5	< 0.5		1.3	0.7	1.18	0.68	< 0.5
16 Hinsdale Place (North Ward)	No Data											
85 Astor Street (South Ward)	No Data											

*Pb = lead; Si = silica; Fe = iron; Al = aluminum; Mn = manganese; Na = sodium; O= oxygen; Mg=mangnesium; P=phosphorous; Ca= calcium

[1] By combustion

Note: No data infers the mineral phase was either not present or below the detection limit

5.2.2 14 Hinsdale Place

The outermost layer had the greatest amount of silica (Si), iron (Fe), aluminum (Al), manganese (Mn), and oxygen (O) which substantially decreased in the subsequent layers. The high level of silica (Si) in the outermost layer is likely due to the quartz grains in the trench sediments that were scattered over the scale surface. The elements that were greater in the outermost three layers and then substantially decreased in the innermost layer, were phosphorous (P), calcium (Ca) and carbon (C). Both the phosphorous (P) and calcium (Ca) concentrations correspond with the scale composition consisting of predominantly a calcium-hydroxypyromorphite mineral phase in the outermost three layers, which forms in the presence of phosphate. Other elements were traced in the lead layers, but were less than 0.5% by weight, such as magnesium (Mg), sodium (Na), sulfur (S), titanium (Ti), and potassium (K). It should be noted that trench sediment was observed on the scale surface and contained visible mica and small rock fragments.

The outermost layer had the lowest amount of lead (Pb), which significantly increased in the innermost layers. The general trend of increasing Pb from the outer to inner layers corresponds to the scale composition consisting of calcium lead phosphate hydroxide (calcium-hydroxypyromorphite) to a mix of lead carbonate and PbO in L5. The increase in Pb in the layers moving from outer to inner is expected, as the inner layers are closer to the source of lead (the pipe).

5.2.3 285 Chestnut Street

The outermost layer had the greatest amount of carbon (C), aluminum (Al), silica (Si), phosphorous (P), chloride (Cl), tin (Sn), manganese (Mn), and iron (Fe), which substantially decreased in the subsequent layers. Calcium (Ca) was also higher in the outermost layer, increased in the second layer and decreased substantially in the subsequent layers. Other elements were traced in the lead layers, but were less than 0.5% by weight, such as sulfur (S), chromium (Cr), copper (Cu), zinc (Zn), and nickel (Ni).

The outermost layer had the lowest amount of lead (Pb), which significantly increased in the innermost layers. The general trend of increasing Pb from the outer to inner layers corresponds to the scale composition consisting of predominantly a calcium-hydroxypyromorphite mineral phase in the outermost two layers. The increase in Pb in the layers moving from outer to inner is expected, as the inner layers are closer to the source of lead (the pipe). The calcium-hydroxypyromorphite mineral phase was also predominant in the 14 Hinsdale Place lead pipe.

5.2.4 16 Hinsdale Place

Due to disturbance of the lead pipe scale during excavation, it was not possible to complete the elemental analysis and XRD analysis for this scale. However, a cross sectional analysis was performed via SED/EMS mapping and indicates the scale appears to be consistent with what was found in 14 Hinsdale Place (i.e., predominantly calcium-hydroxypyromorphite, which forms in the presence of phosphate).

5.2.5 85 Astor Street

Also due to disturbance of the scales, it was not possible to complete the elemental analysis. However, a small patch of what was believed to be relatively undisturbed scale was able to be analyzed to identify the crystalline mineral compounds. It should be noted that it cannot be certain that the scale was undisturbed. Based on the data available, the lead scale consisted predominantly of plattnerite and had trace amounts of calcium-hydroxypyromorphite, whereas calcium-hydroxypyromorphite was predominant in the 14 Hinsdale Place and 285 Chestnut Street lead pipe scales and plattnerite was predominant in the 95 Pennsylvania Avenue lead pipe scale.

5.3 Analysis of Results

5.3.1 Comparison of Sequential Sampling Results and Scale Analysis

More dominant plattnerite scales were found on the pipes harvested in 95 Pennsylvania Avenue and 85 Astor Street, but there was also plattnerite found in the scale for 14 Hinsdale. Plattnerite is a tetravalent lead scale and is similar to what was found on the scales in the Pequannock Gradient. However, unlike Pequannock, the plattnerite scales in the Wanaque Gradient appear to be stable and effectively controlling lead release. Calcium-hydroxypyromorphite, which are stable crystalline compounds formed in the presence of phosphate presumably from the orthophosphate addition, were found as the dominant scales at 14 Hinsdale Place, 16 Hinsdale Place and 285 Chestnut Avenue. A summary of the dominant scales and related water quality data are provided in **Table 5-3.**

In December 2018 and January 2019, Newark closed the partially open division gate valves that caused Pequannock water to flow into the Wanaque Gradient. The flushed water samples during the sequential sampling showed higher levels of orthophosphate in the samples that were taken after the division gates were closed compared with the samples taken prior to the division gates being closed. However, the orthophosphate levels did not always align with a dominant calcium-hydroxypyromorphite crystalline scale in the samples tested. For example, low concentrations of orthophosphate were found at 14 Hinsdale Place, however a calcium-hydroxypyromorphite scale was observed. Conversely, orthophosphate was present in the water at 95 Pennsylvania Avenue and 85 Astor Street, yet a calcium-hydroxypyromorphite crystalline scale was not the dominant scale in these locations.

The scale analyses conducted on LSLs in the Wanaque Gradient is an example that, even with orthophosphate addition, a phosphate-based crystalline scale is not necessarily the solubility-controlling phase. For this specific system, while the scale morphology varies throughout the system, the scales appear to be functioning to control lead solubility. This is evidenced by the majority of low lead levels at the tap in the LCR compliance sampling and the low lead levels found in the sequential sampling performed for this study.

Table 5-3 – Comparison of Water Quality Data and EPA Scale Analysis Results

Address	Chlorine Residual (mg/L)		pH		Orthophosphate (mg/L PO4)		Date Sampled[1]	Date Excavated	Most Prominent Scale Compound Found
	1st/2nd Liter	Flushed Sample	1st/2nd Liter	Flushed Sample	1st/2nd Liter	Flushed Sample			
95 Pennsylvania Avenue (South Ward)	N/A	N/A	N/A	N/A	1.19	1.64	12/14/18	12/21/18	Plattnerite > cerrusite > litharge
85 Astor Street (South Ward)	0.93	0.89	7.8	7.78	1.56	1.56	4/16/19	5/23/19	Plattnerite > litharge > cerrusite > calcium-hydroxypyromorphite
14 Hinsdale Place (North Ward)	N/A	N/A	N/A	N/A	<0.3	<0.3	12/14/18	12/21/18	Calcium-hydroxypyromorphite > cerrusite > plattnerite
16 Hinsdale Place (North Ward)	0.19	0.67	6.6	6.63	<0.3	2.30	1/21/19	3/12/19	Calcium-hydroxypyromorphite
285 Chestnut Street (East Ward)	0.03	0.36	6.25	6.36	1.99	2.10	1/11/19	2/2/19	Calcium-hydroxypyromorphite > cerrusite > litharge

[1] The water quality provided is from testing before the LSLR.

Section 6

Recommendations

Based on the information available and presented herein, CDM Smith does not recommend modifications to the corrosion control treatment for the Wanaque Gradient at this time. The Wanaque Gradient has not experienced concerning levels of soluble and particulate lead that are currently being experienced in the Pequannock Gradient.

Based on the scale analyses, the corrosion control mechanism in the Wanaque Gradient is currently a combination of phosphate crystalline scales (calcium-hydroxypyromorphite), plattnerite (tetravalent lead) scales and carbonate scales. The scales are providing protection against lead corrosion which is evident in the LCR compliance tap sampling and the sequential sampling that was performed for this study. Therefore, it is not recommended that treatment or corrosion control parameters be modified in the Wanaque Gradient for the purposes of further improving lead corrosion control.

Several factors may be contributing to the makeup and stability of the scales in the Wanaque Gradient including:

- An orthophosphate dose of 1.8 to 2.2 mg/L as PO_4 operating within an effective pH range
- Robust treatment at the NJDWSC plant, including clarification for organics removal
- Stable water quality making the system less vulnerable to seasonal changes

In addition to effective corrosion control treatment, there are measures the City can take to help further protect residents from lead in drinking water when there are lead-containing materials in their home plumbing:

- **Public Education** – It is recommended that the City continue with the public education campaign to encourage residents to understand the risks of lead in their drinking water when they have a lead service line or lead solder in copper plumbing.
- **Lead Service Line Replacement Program** – The City has embarked on a city-wide lead service line replacement program to replace the homeowner-owned lead service line with a copper line for $1,000 to anyone within the City of Newark. The City should continue to encourage homeowners and landlords to sign up for this program.
- **Flushing in Wanaque** – Based on the results of the sequential sampling in Newark and in other cities and towns, even with corrosion control treatment, lead particles can migrate through a scale barrier into the drinking water. This particularly occurs after periods of low water usage, stagnation or anything that disturbs a lead service line or lead solder. It is recommended that residents understand the need to flush their lines after a stagnation period or after disturbance. In all 12 sequential sampling events performed within the

Wanaque Gradient, the flushed samples were typically below 2 ppb indicating that the scale is stable and that flushing is an effective means of reducing lead concentrations.

- **Lead Testing at the Tap** – Newark currently provides free lead testing to all residents in Newark. If a test result from a home located in the Wanaque Gradient is above 15 ppb, Newark provides a free filter to that resident.

It is recommended that the City continue to routinely monitor the results from ongoing water quality parameter and compliance sampling to identify and understand any changes that may take place. If ***any*** treatment modifications are proposed by NJDWSC or the City, the impact on the current corrosion control mechanisms would need to be further evaluated.

It is CDM Smith's opinion that optimal WQPs can be set for the Wanaque Gradient at this time to monitor and guide the consistency of the delivered water quality.

Appendix A

Wanaque Pipe Scale Analysis

Newark, NJ

LSL samples extracted in December 2018, and February, March, May 2019

For more information, please contact:

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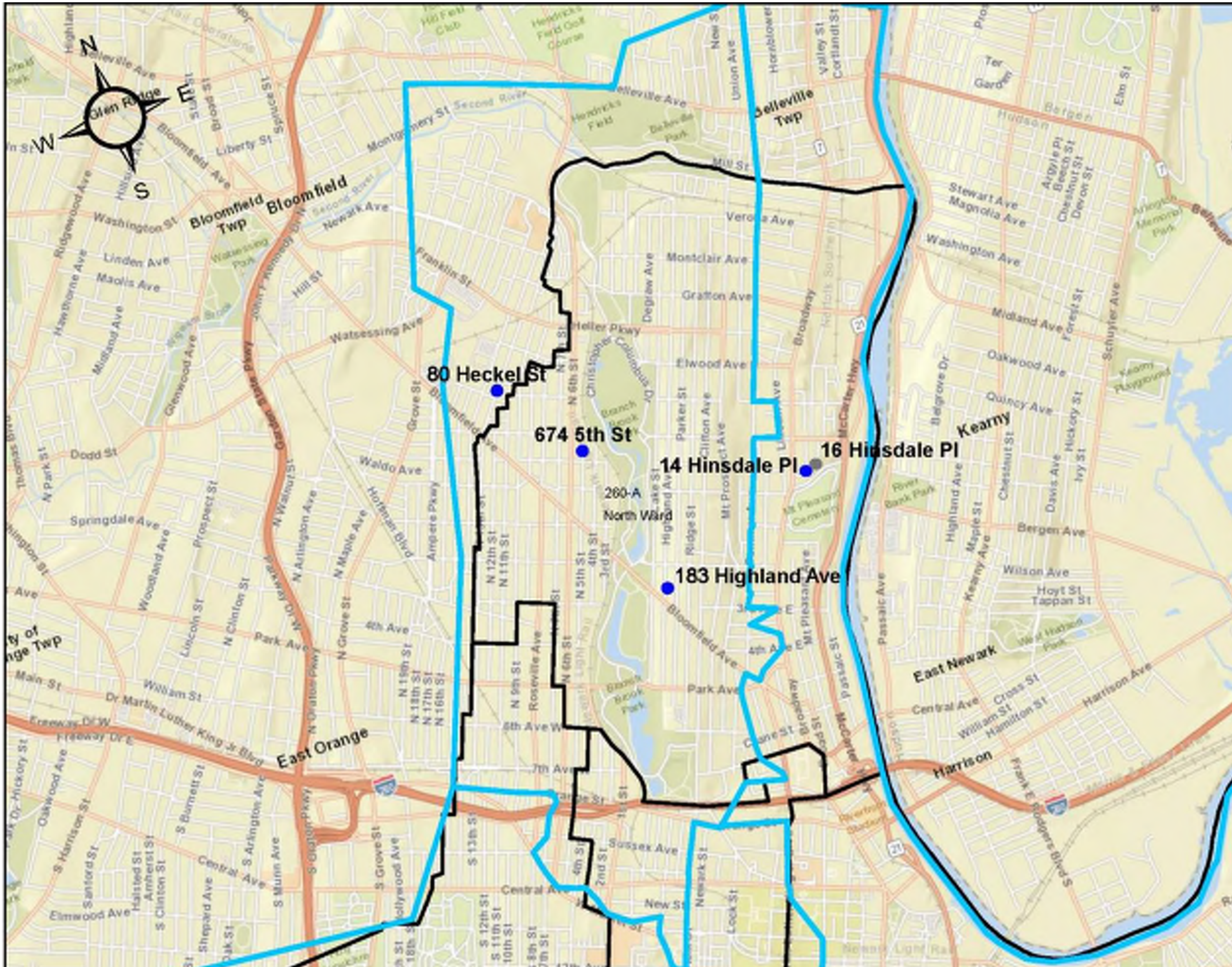
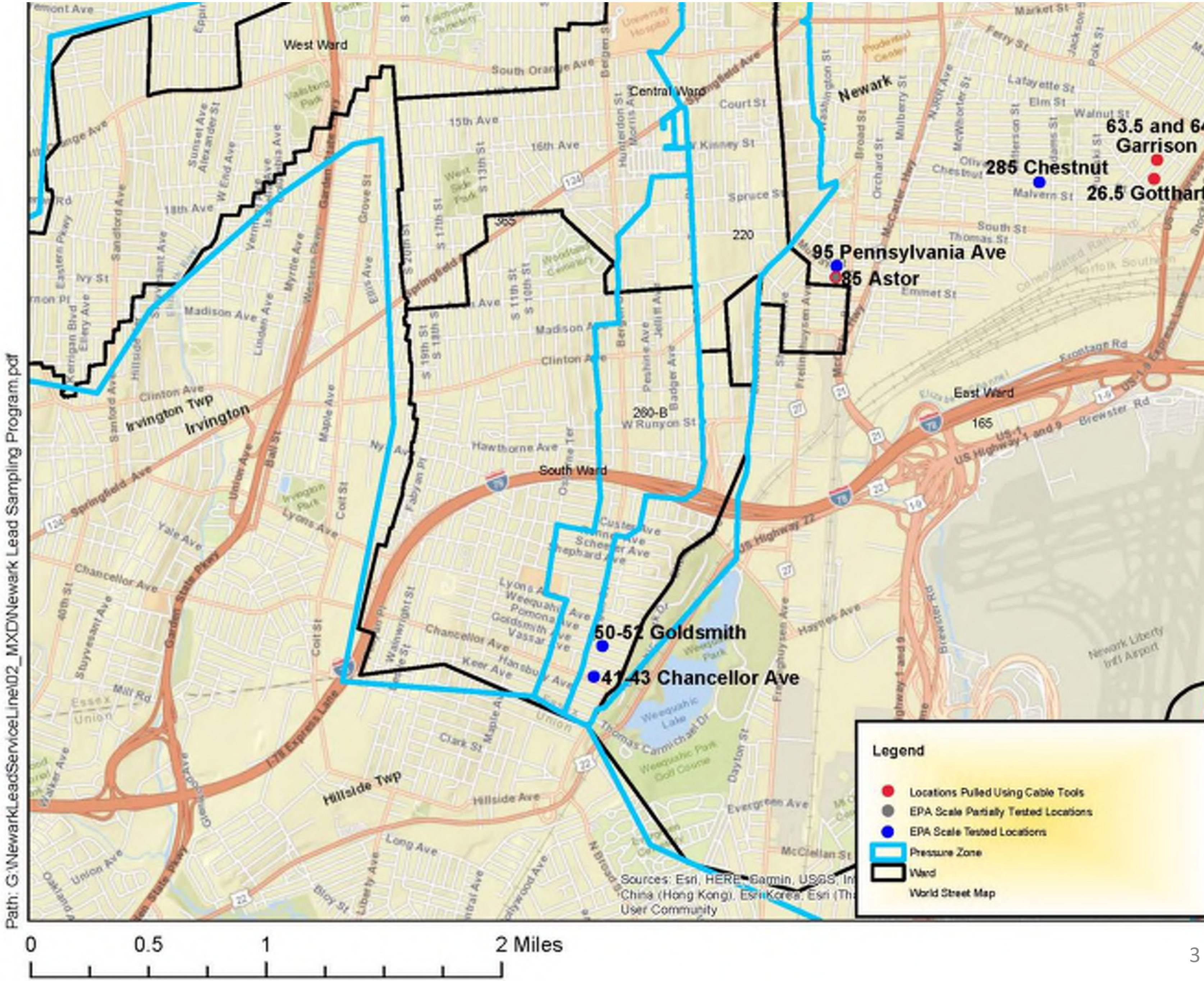

80 Heckel St
674 5th St
14 Hinsdale Pl
16 Hinsdale Pl
183 Highland Ave
260-A
North Ward
Bloomfield
Bloomfield Twp
Belleville Twp
Kearny
East Newark
Harrison
East Orange
N
E
W
S



63.5 and 64 Garrison
285 Chestnut
26.5 Gotthart
95 Pennsylvania Ave
85 Astor
50-52 Goldsmith
41-43 Chancellor Ave
West Ward
Central Ward
East Ward
South Ward
Newark
Irvington
Irvington Twp
Hillside Twp
Legend
Locations Pulled Using Cable Tools
EPA Scale Partially Tested Locations
EPA Scale Tested Locations
Pressure Zone
Ward
World Street Map
0
0.5
1
2 Miles
Path: G:\NewarkLeadServiceLine\02_MXD\Newark Lead Sampling Program.pdf


Newark, NJ
Lead Service Line
Address: 285 Chestnut
Installed: 1910
Removed: 01 February 2019

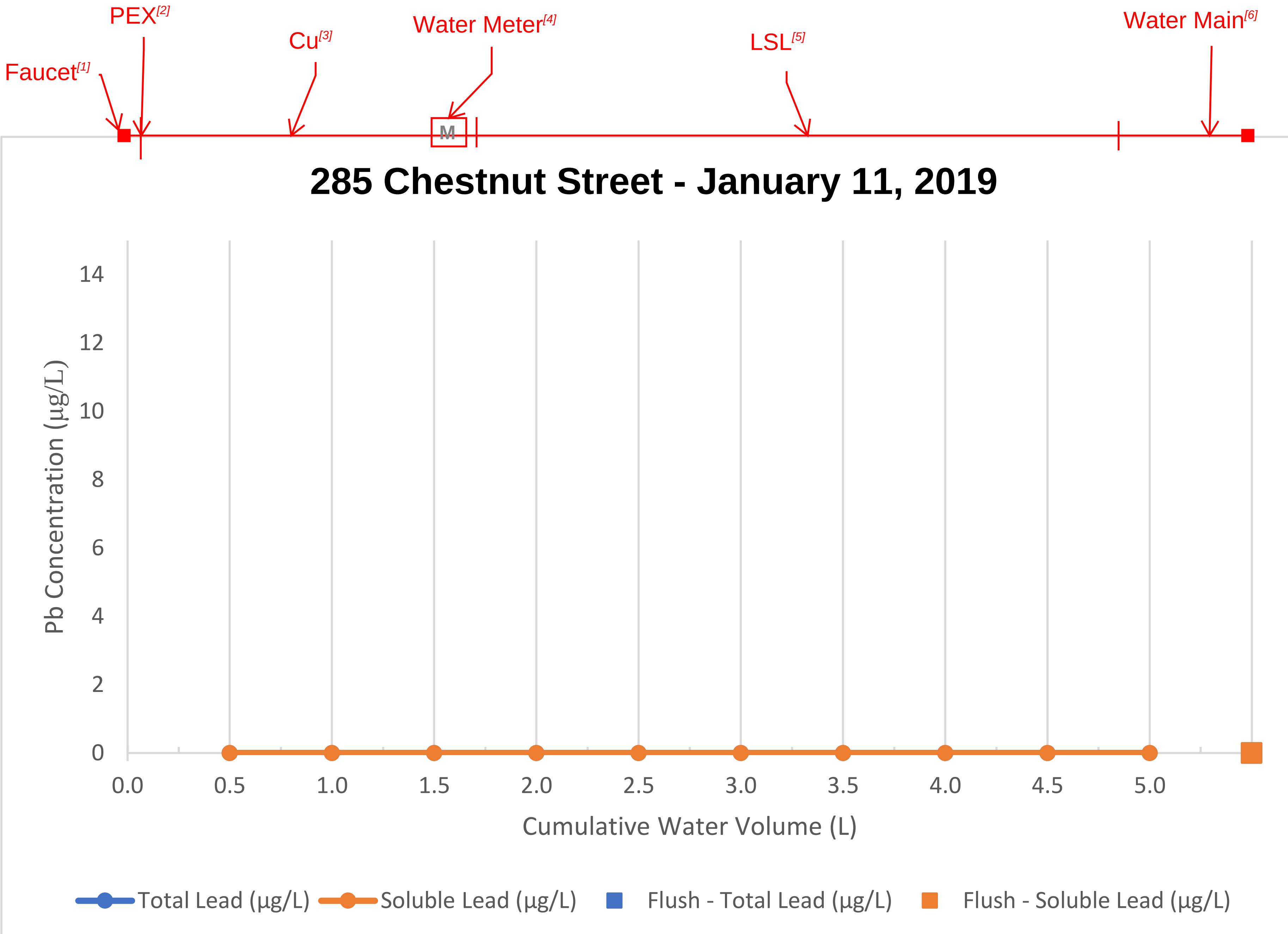
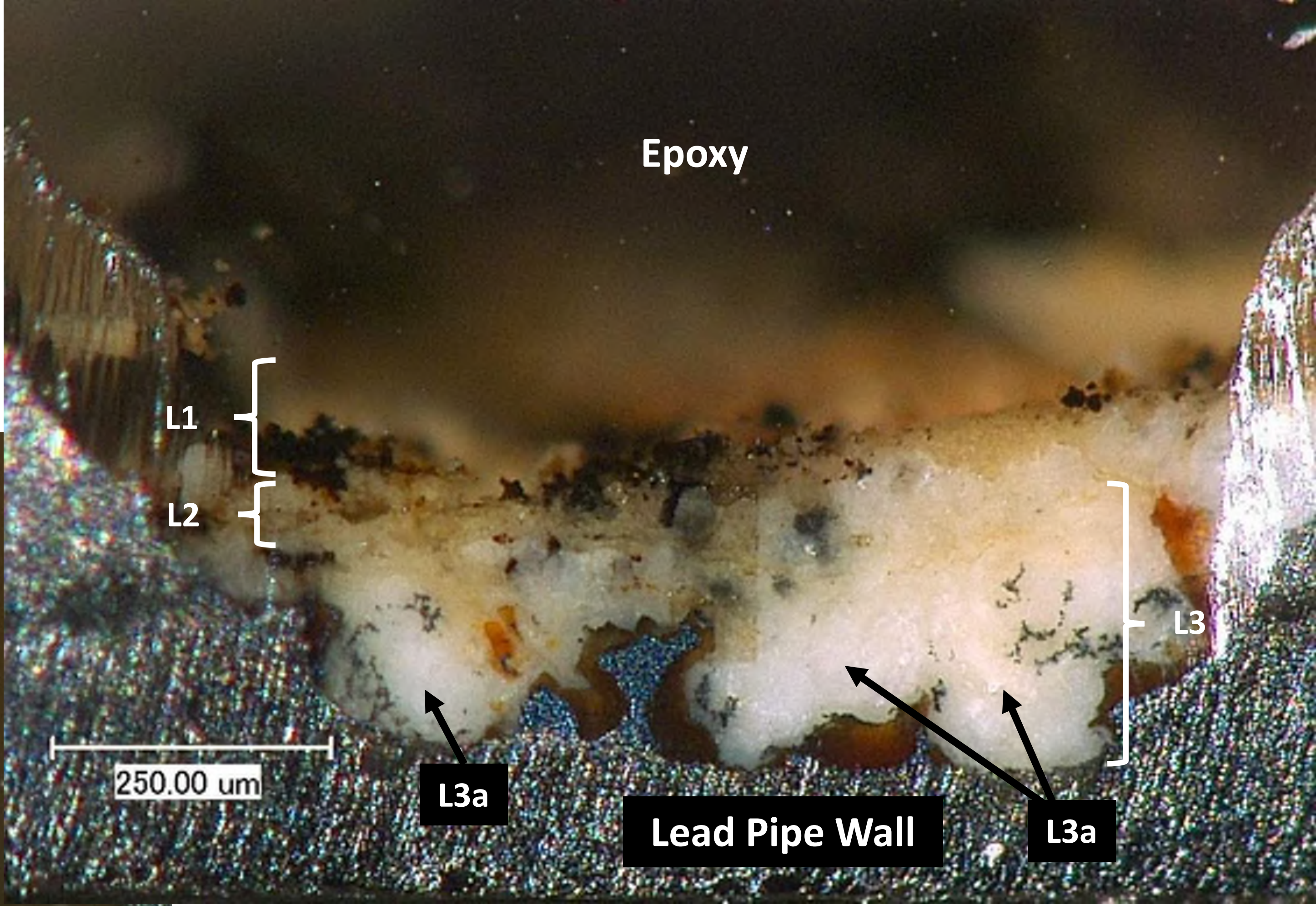

Faucet[1]
PEX[2]
Cu[3]
Water Meter[4]
M
LSL[5]
Water Main[6]
285 Chestnut Street - January 11, 2019
Pb Concentration (µg/L)
0
2
4
6
8
10
12
14
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Cumulative Water Volume (L)
Total Lead (µg/L)
Soluble Lead (µg/L)
Flush - Total Lead (µg/L)
Flush - Soluble Lead (µg/L)

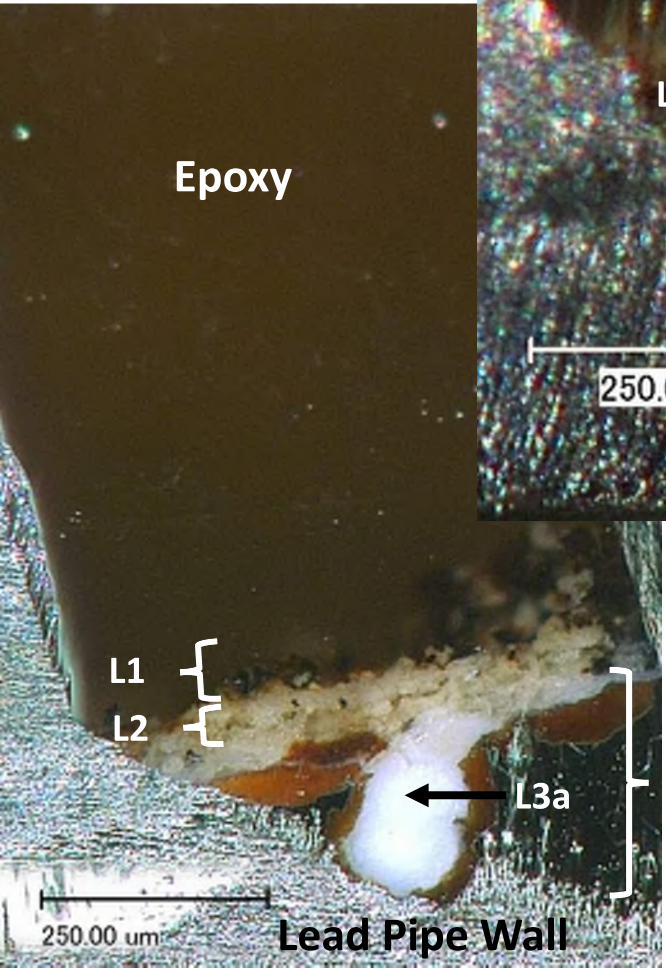
Table 1-1H
City of Newark Sequential Monitoring
Analytical Results
285 Chestnut St

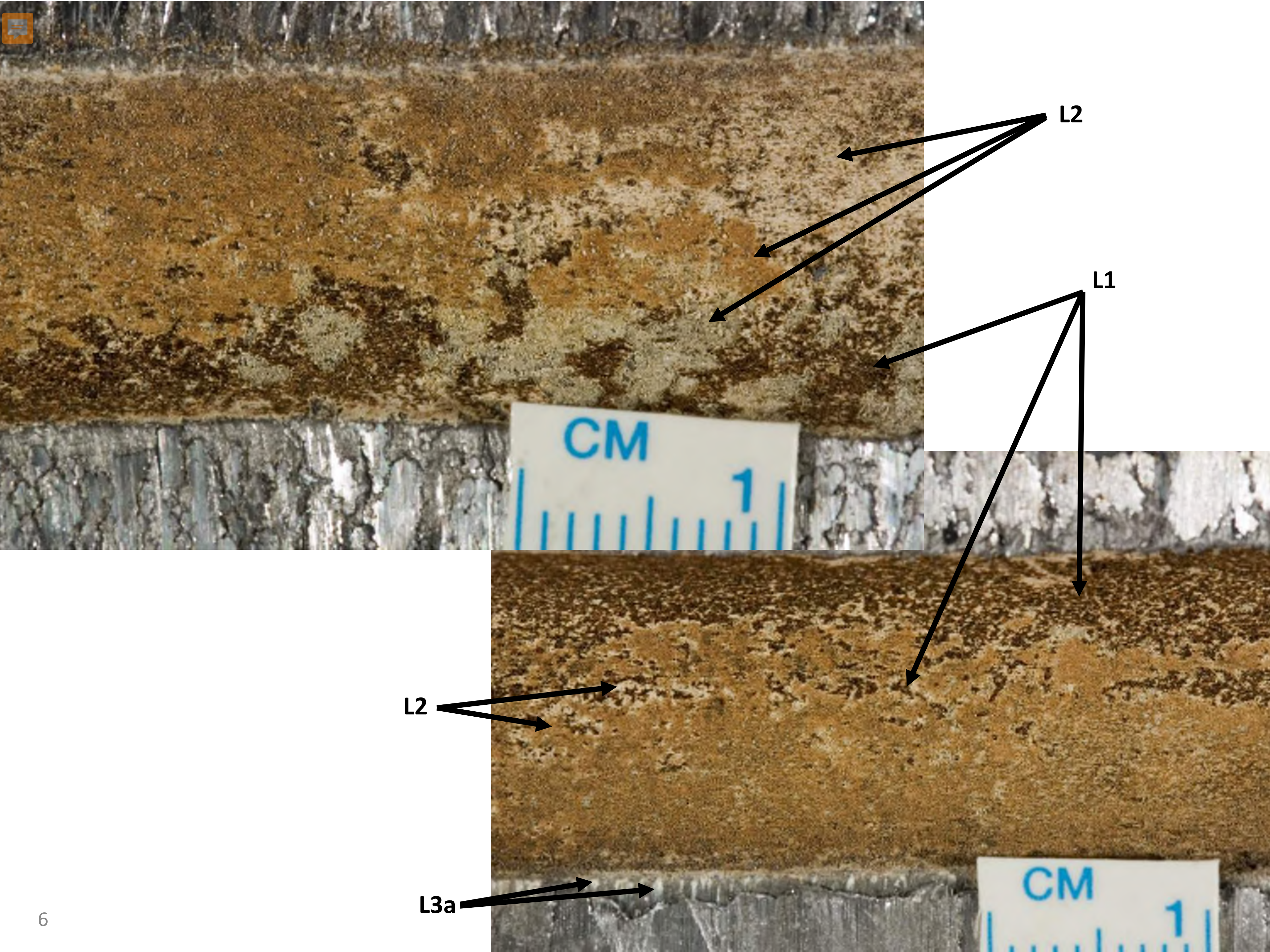
Site H - 1/11/19

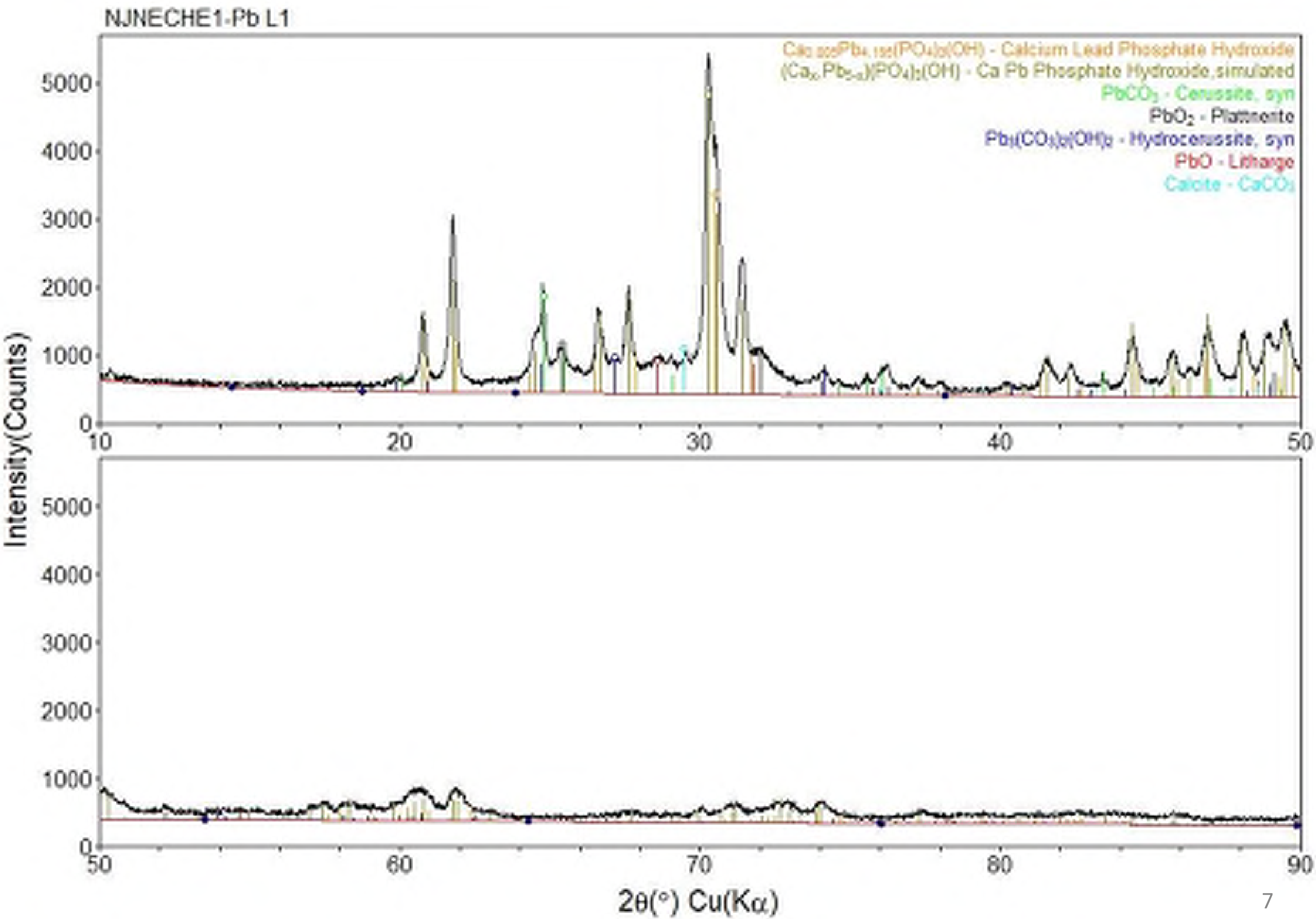
Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters pH[1]	Temp[1] (degrees C)	Free Cl_2[1] (mg/L)	Total Pb (µg/L)	Dissolved Pb (µg/L)	Total Cu (mg/L)	Alk. (mg/L as $CaCO_3$)	Cond. umhos/cm	Orthophosphate (mg/L as P)	Silica (mg/L as SiO2)	Location/ Description
H1	500	500	After Stagnation	6.25	17.4	0.03	<2	<2	<.05	32.0	243			Faucet (6% Black PEX or Black SS Braided) and Copper Piping with No Lead Solder (97%)
H2	500	1000	After Stagnation				<2	<2	<.05			0.663	3.46	Copper Piping(100%)
H3	500	1500	After Stagnation				<2	<2	<.05					Lead Piping (100%)
H4	500	2000	After Stagnation				<2	<2	<.05					Lead Piping (100%)
H5	500	2500	After Stagnation				<2	<2	<.05					Lead Piping (100%)
H6	500	3000	After Stagnation	6.3	18	0.14	<2	<2	<.05	32	242		3.76	Lead Piping (100%)
H7	500	3500	After Stagnation				<2	<2	<.05			0.705		Lead Piping (100%)
H8	500	4000	After Stagnation				<2	<2	<.05					Lead Piping (100%)
H9	500	4500	After Stagnation				<2	<2	<.05					Lead Piping (100%)
H10	500	5000	After Stagnation				<2	<2	<.05					Lead Piping (50%); Water Main (50%)
H11 FLUSH	500	5500	Flushed after the sequential sampling	6.36	20	0.36	<2	<2	<.05	31.0	240	0.7	3.75	Water Main (100%)

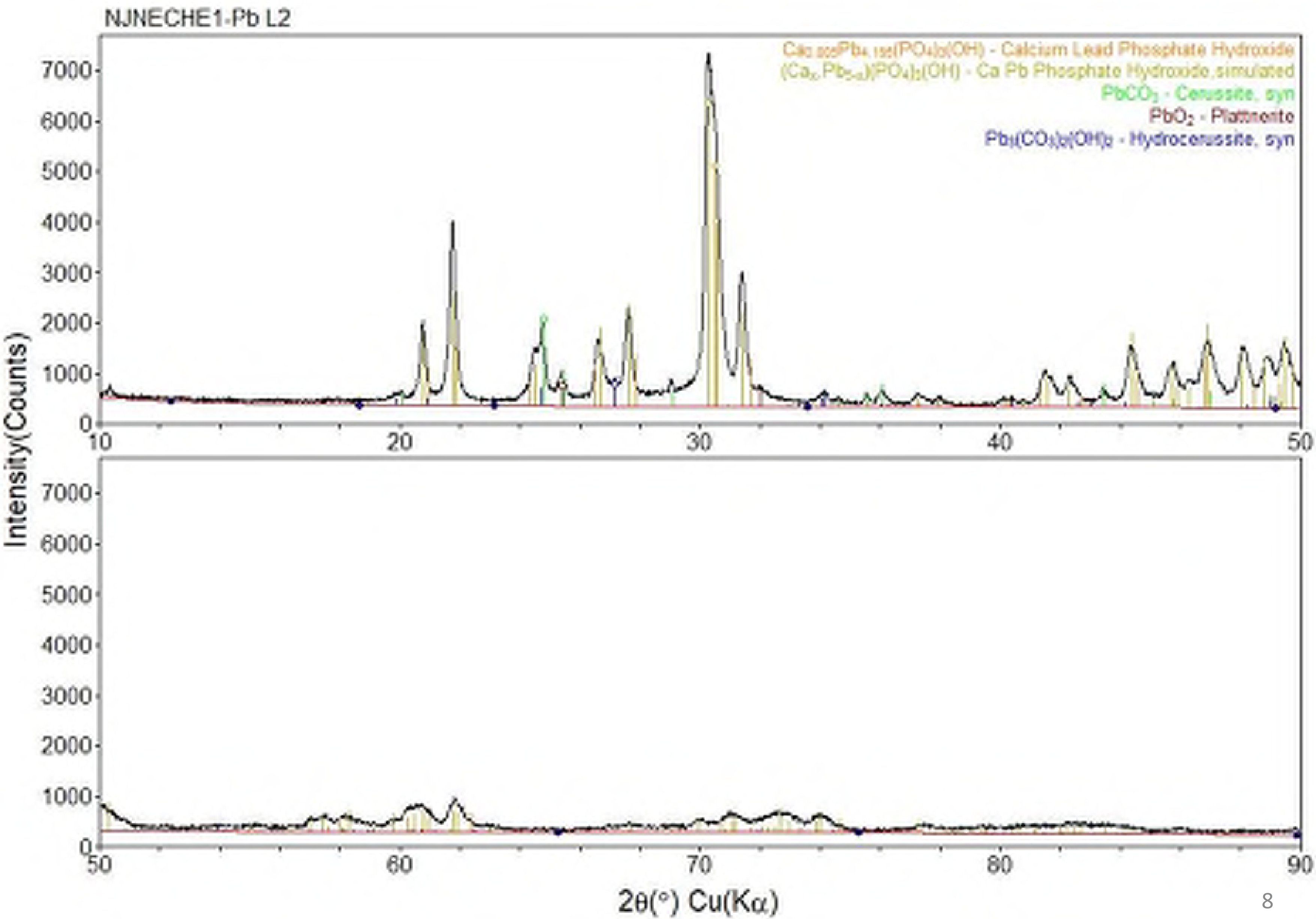
NOTES
1. pH, temperature, and free and total chlorine will be field measured.
2. **HOMEOWNER SHOULD FLUSH THE LINE FOR 10 MINUTES BEFORE BEGINNING STAGNATION PERIOD (i.e. night before sampling).**


Epoxy
L1
L2
L3
L3a
250.00 um
Lead Pipe Wall
L3a

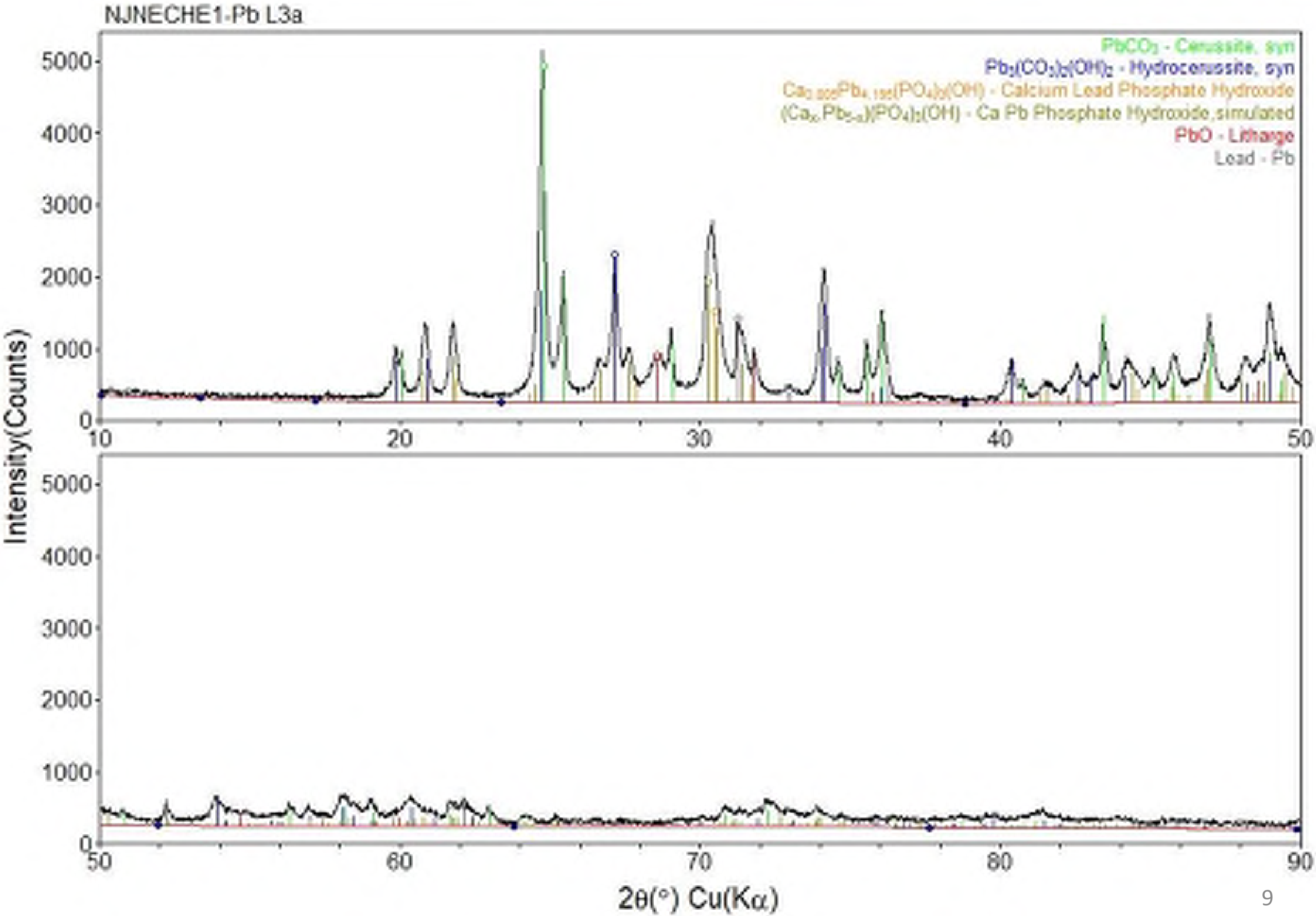

Epoxy
L1
L2
L3a
L3
250.00 um
Lead Pipe Wall

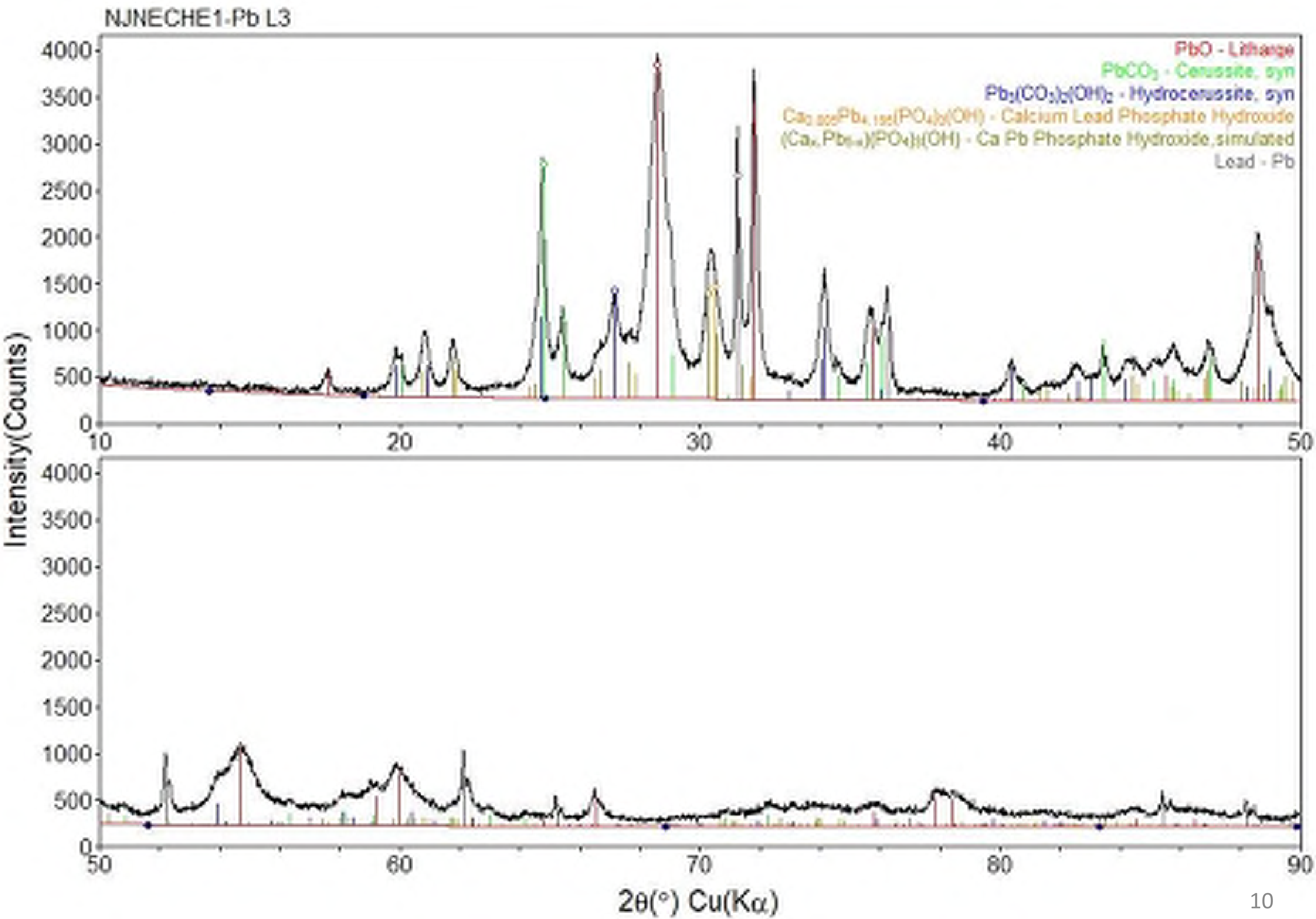

L2
L1
CM
1
L2
L3a
CM
1

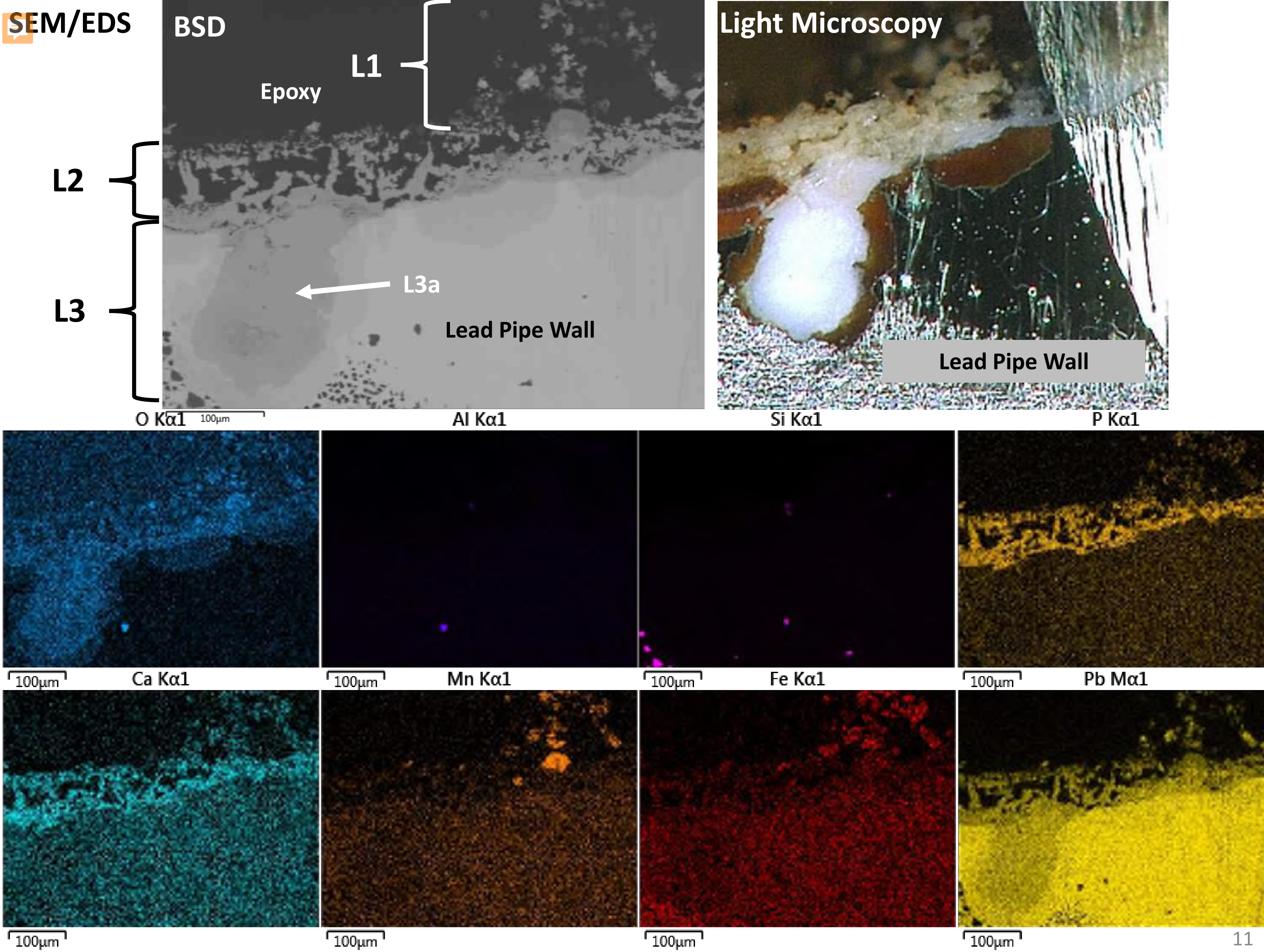

NJNECHE1-Pb L1
Calcium Lead Phosphate Hydroxide
$(Ca_x,Pb_{5-x})(PO_4)_3(OH)$ - Ca Pb Phosphate Hydroxide,simulated
$PbCO_3$ - Cerussite, syn
PbO_2 - Plattnerite
$Pb_3(CO_3)_2(OH)_2$ - Hydrocerussite, syn
PbO - Litharge
Calcite - $CaCO_3$
Intensity(Counts)
0
1000
2000
3000
4000
5000
10
20
30
40
50
60
70
80
90
2θ(°) Cu(Kα)



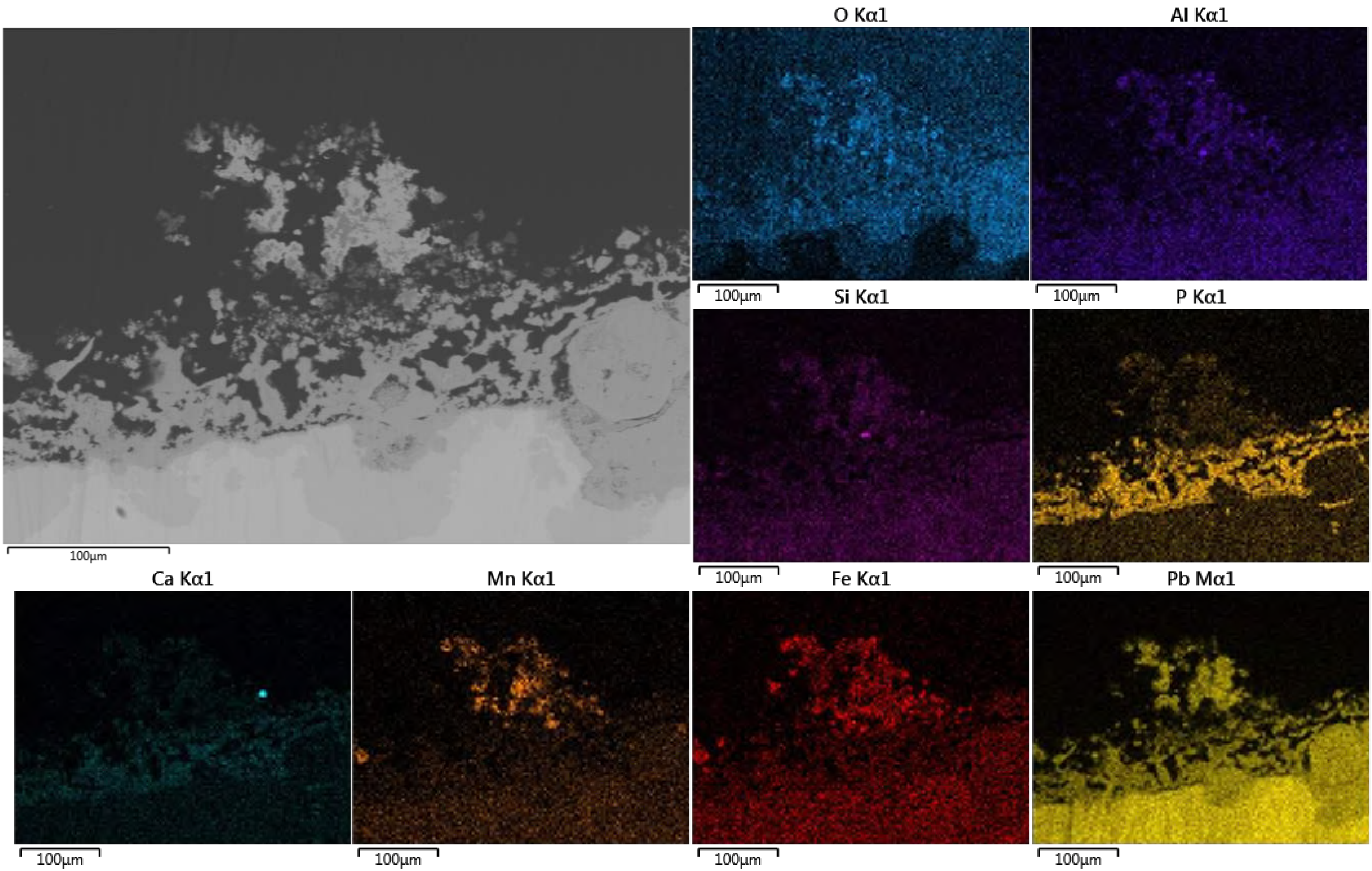
NJNECHE1-Pb L2
- Calcium Lead Phosphate Hydroxide
- Ca Pb Phosphate Hydroxide,simulated
$PbCO_3$ - Cerussite, syn
PbO_2 - Plattnerite
- Hydrocerussite, syn
Intensity(Counts)
0
1000
2000
3000
4000
5000
6000
7000
10
20
30
40
50
60
70
80
90
2θ(°) Cu(Kα)


NJNECHE1-Pb L3a
PbCO3 - Cerussite, syn
Pb3(CO3)2(OH)2 - Hydrocerussite, syn
Calcium Lead Phosphate Hydroxide
Ca Pb Phosphate Hydroxide,simulated
PbO - Litharge
Lead - Pb
Intensity(Counts)
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
90
2θ(°) Cu(Kα)

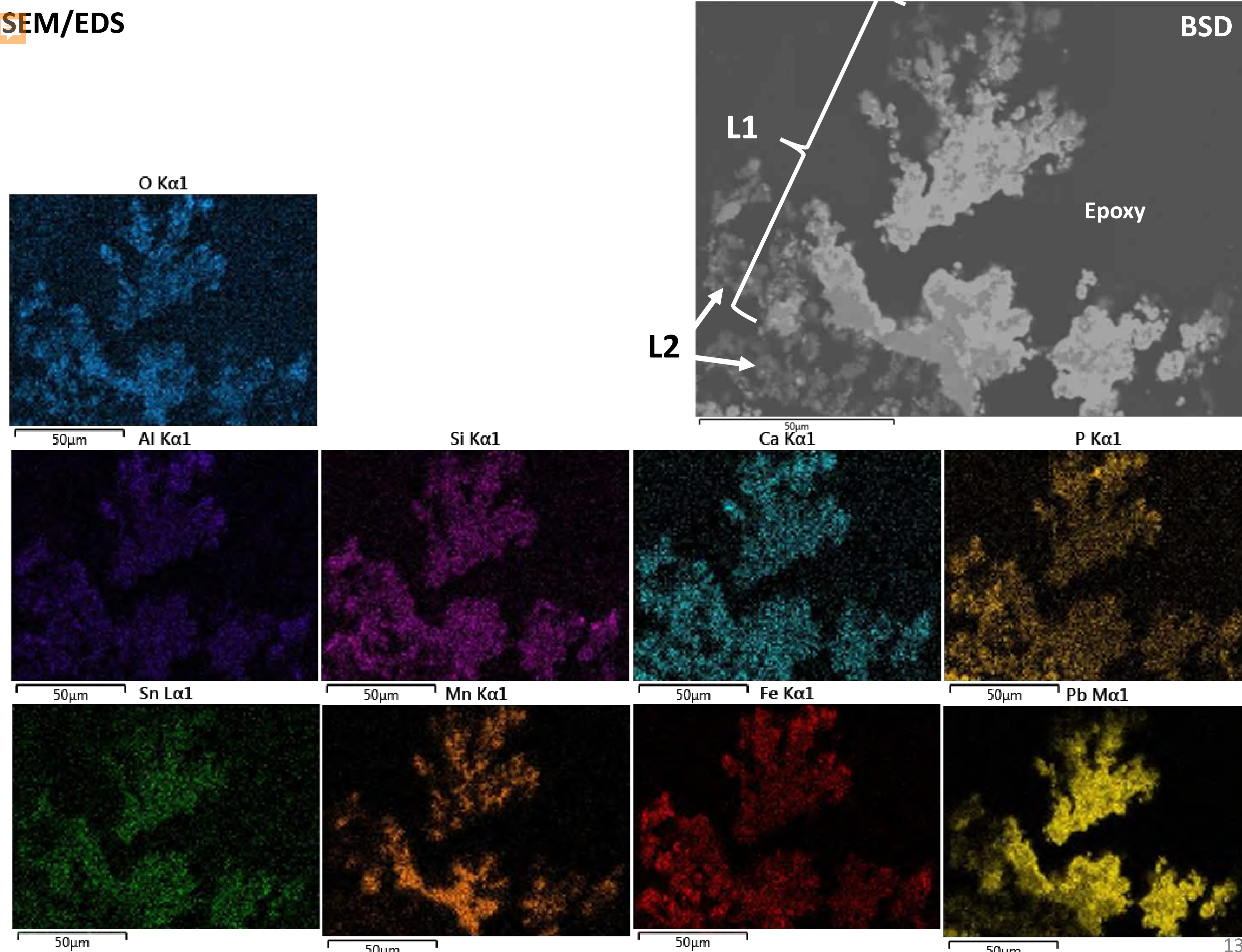

NJNECHE1-Pb L3
PbO - Litharge
$PbCO_3$ - Cerussite, syn
$Pb_3(CO_3)_2(OH)_2$ - Hydrocerussite, syn
Calcium Lead Phosphate Hydroxide
Ca Pb Phosphate Hydroxide,simulated
Lead - Pb
Intensity(Counts)
2θ(°) Cu(Kα)


SEM/EDS
BSD
Epoxy
L1
L2
L3
L3a
Lead Pipe Wall
Light Microscopy
Lead Pipe Wall
O Kα1
100µm
Al Kα1
Si Kα1
P Kα1
100µm
Ca Kα1
100µm
Mn Kα1
100µm
Fe Kα1
100µm
Pb Mα1
100µm
100µm
100µm
100µm

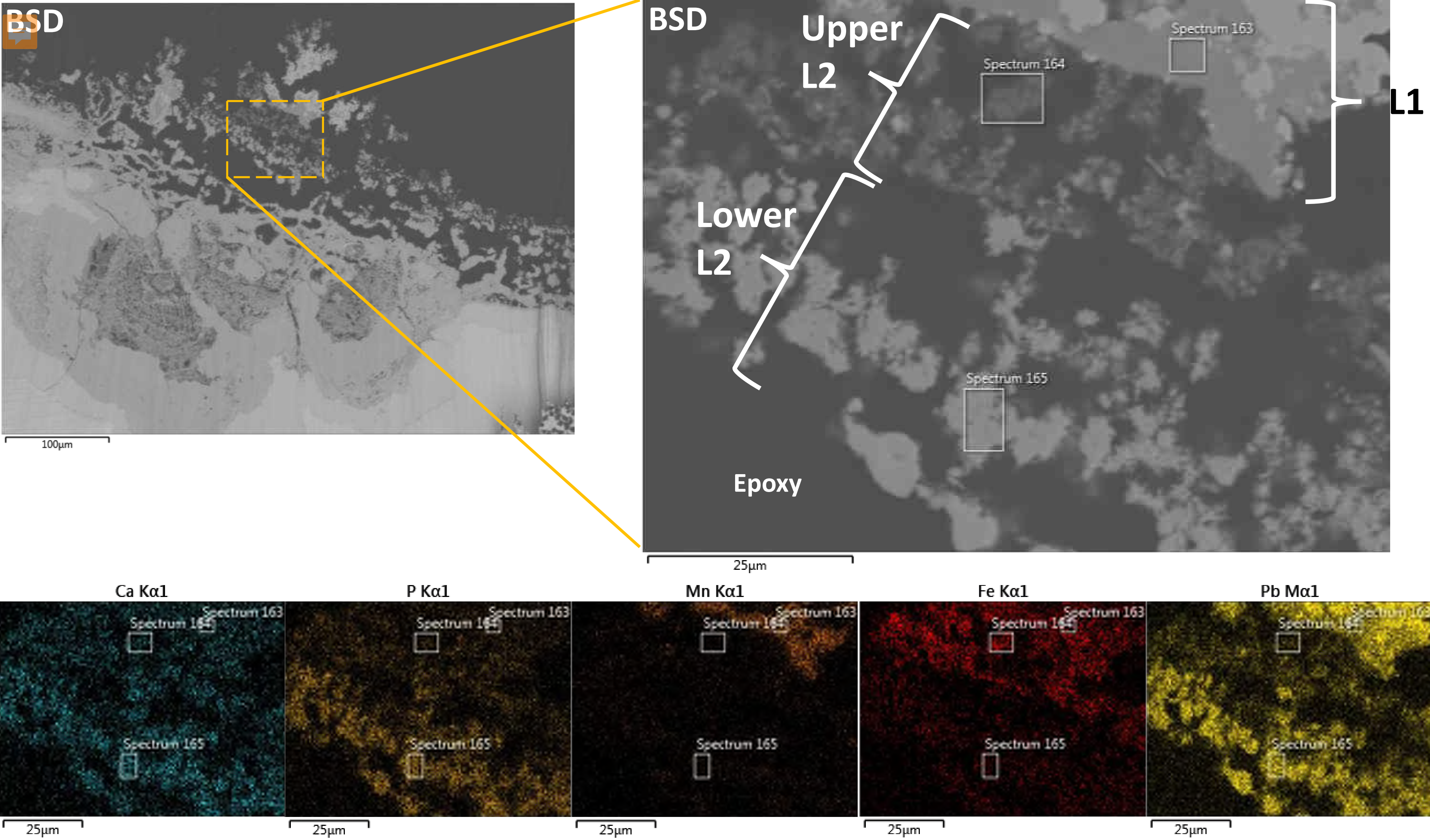
SEM/EDS



SEM/EDS



BSD
L1
L2
Epoxy
50µm
O Kα1
Al Kα1
Si Kα1
Ca Kα1
P Kα1
Sn Lα1
Mn Kα1
Fe Kα1
Pb Mα1

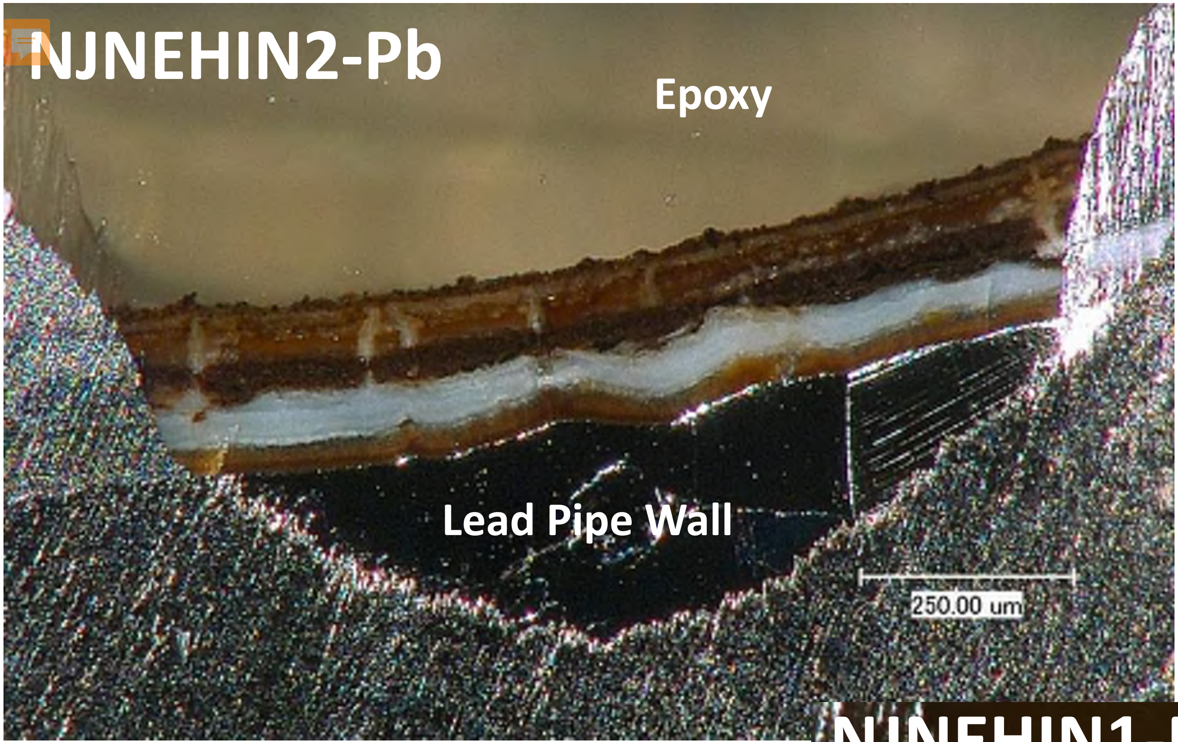


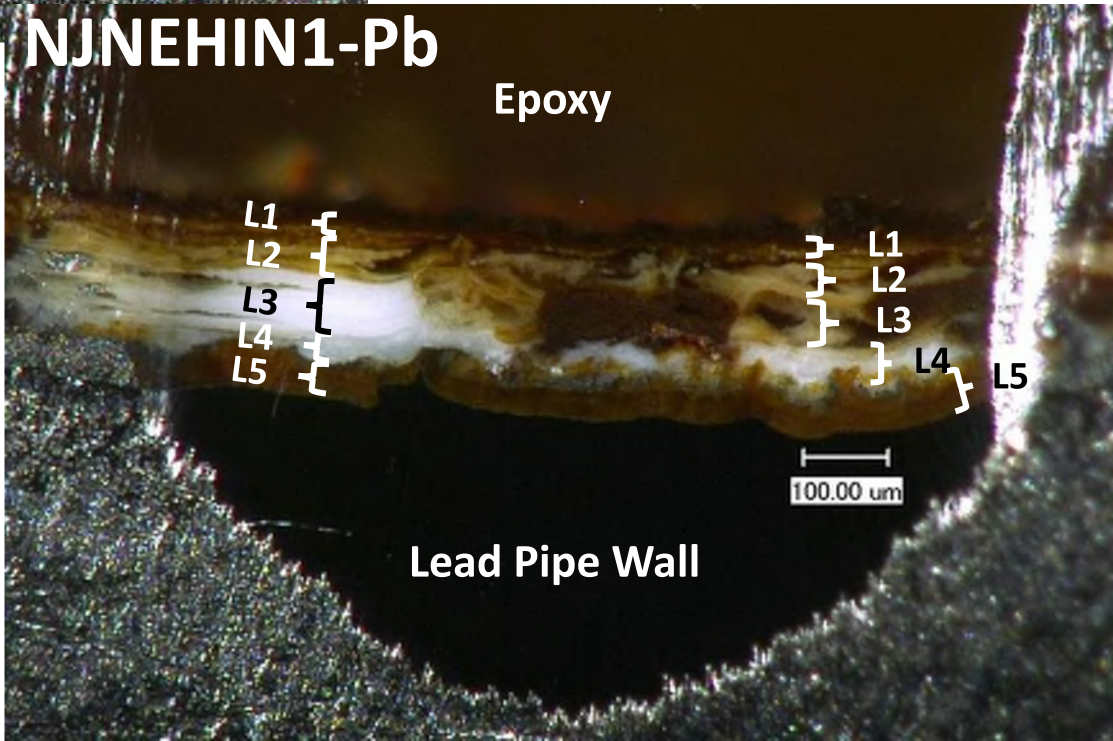
Spectrum #	Elements in Decreasing Abundance
163	Pb, Mn, Fe, P, Si, Ca, Al, V, Sn, Mg
164	Pb, Fe, P, Si, Ca, Mn, Al, Sn, Mg (* less Mn than 163)
165	Pb, P, Ca, Al, Mg

XRF Results
Elemental Concentrations as Average wt%

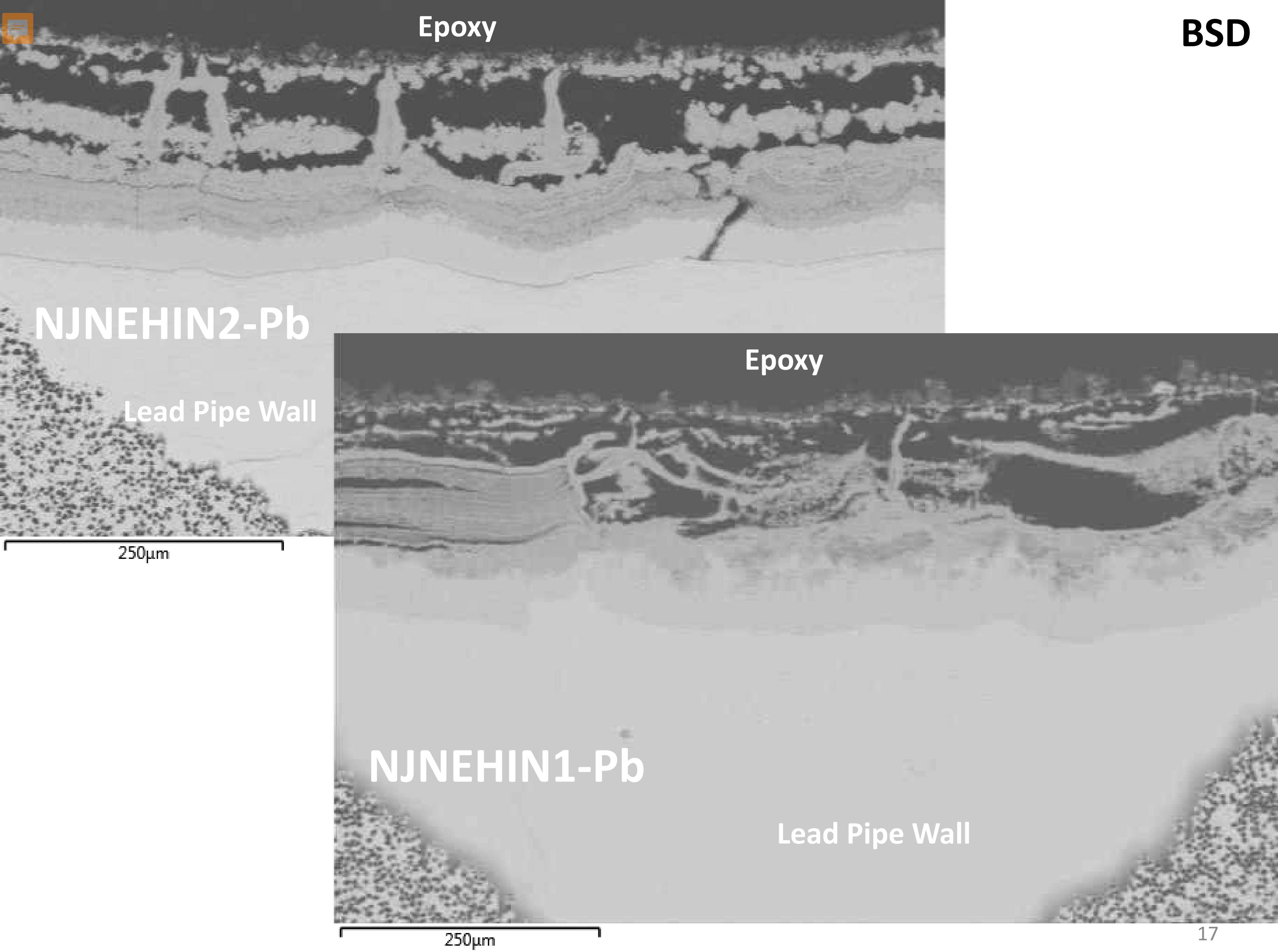
NJNECHE1-Pb				
Elements	**L1**	**L2**	**L3a**	**L3**
***C**	1.21	1.29	2.39	1.18
Al	0.77	0.4	0.61	0.24
Si	1	0.18	0.29	0.073
P	4.9	7.4	2.4	1.3
***S**	0.13	0.12	0.36	0.12
Ca	3	4	1.3	0.7
Cl	1.3	2.1	0.81	0.68
Cr	0.044	-	-	-
Cu	0.23	0.1	0.2	0.09
Sn	0.5	0.41	-	0.2
Zn	0.055	0.033	-	-
Mn	2.6	0.54	0.11	0.041
Fe	2.6	0.45	0.19	0.08
Ni	0.026	0.036	0.11	-
Pb	78	82	88	98

*C and S by combustion


NJNEHIN2-Pb
Epoxy
Lead Pipe Wall
250.00 um

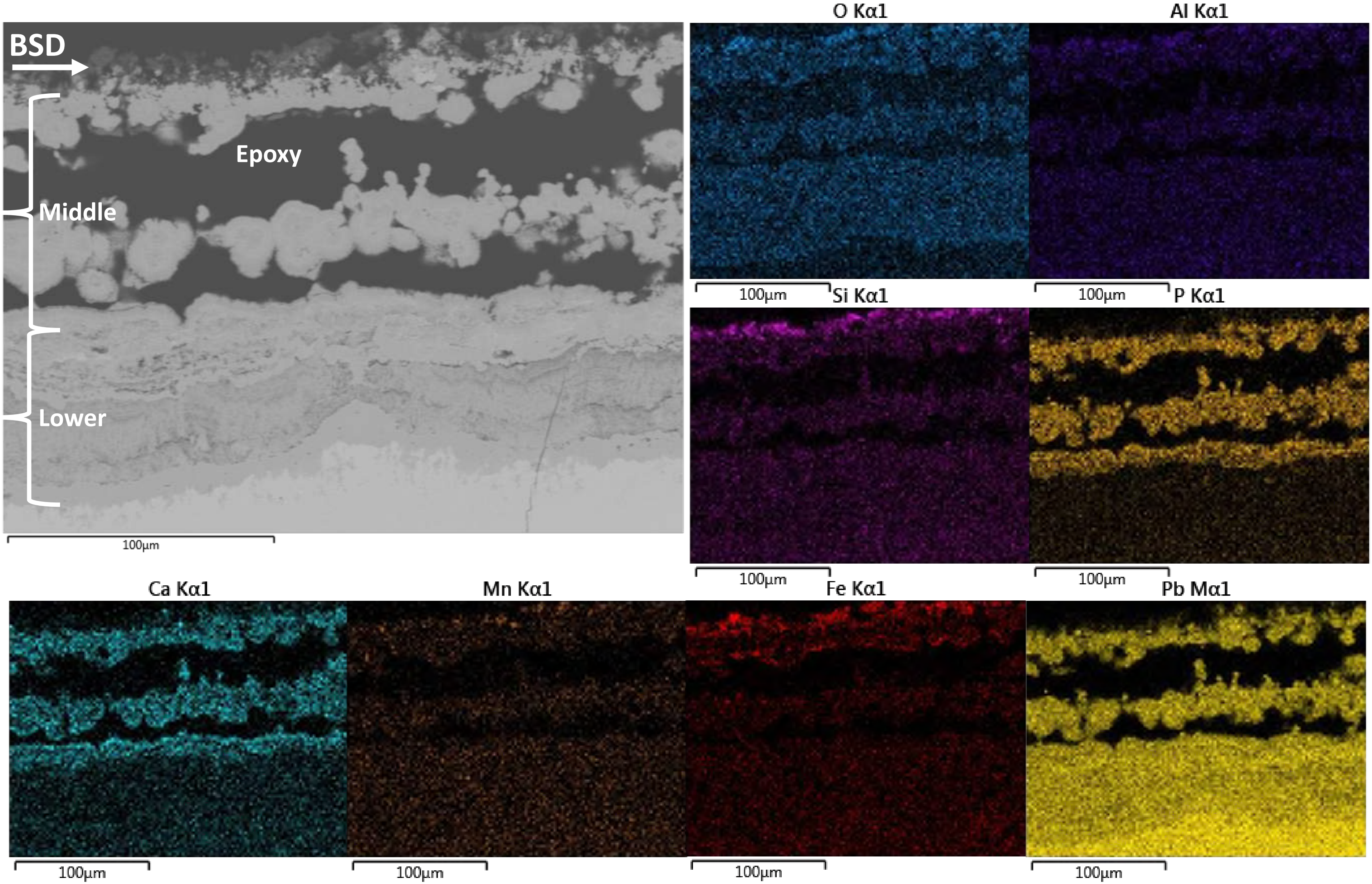

NJNEHIN1-Pb
Epoxy
L1
L2
L3
L4
L5
L1
L2
L3
L4
L5
100.00 um
Lead Pipe Wall

BSD


Epoxy
NJNEHIN2-Pb
Lead Pipe Wall
250µm
Epoxy
NJNEHIN1-Pb
Lead Pipe Wall
250µm

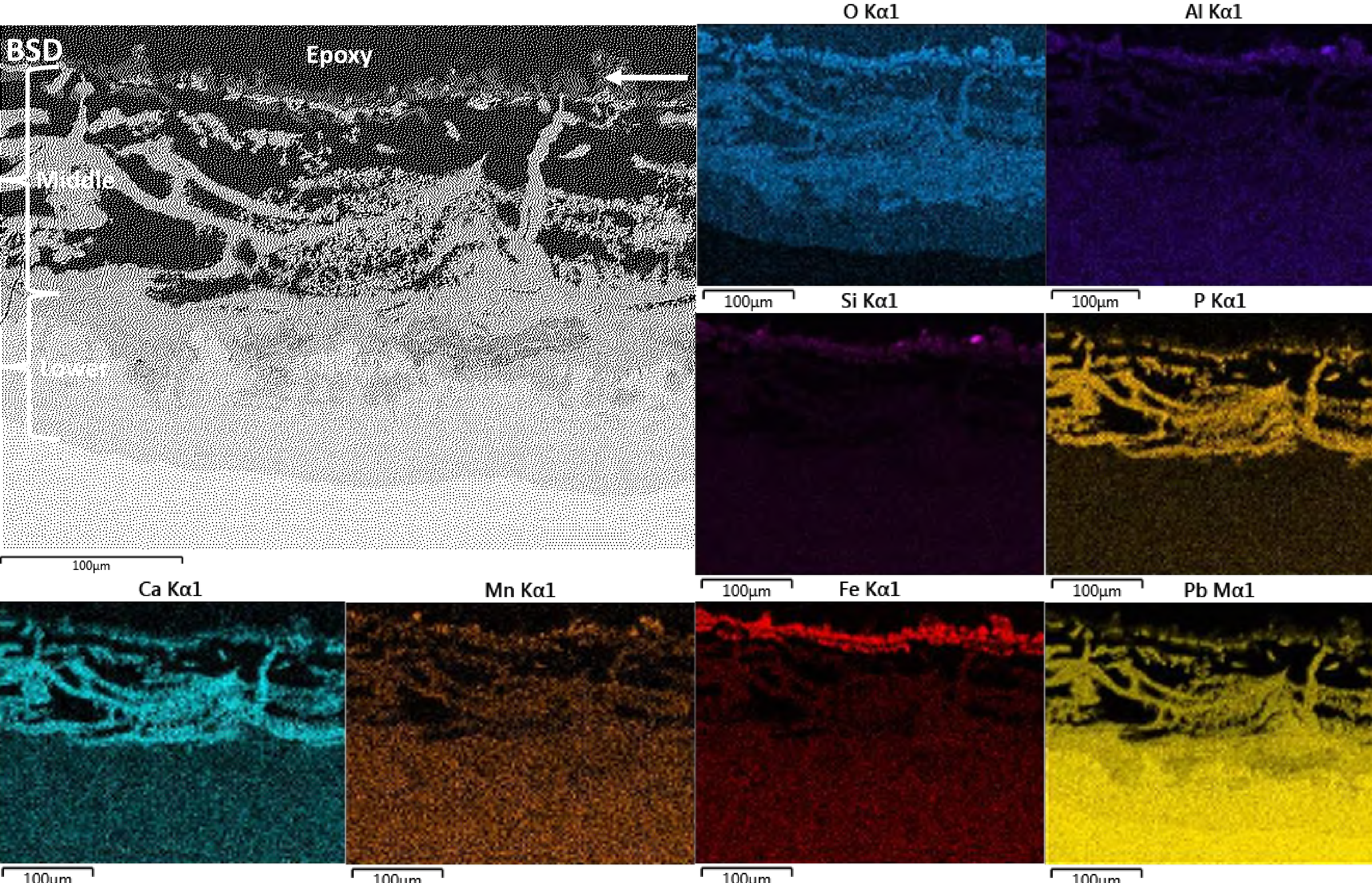
NJNEHIN2-Pb

SEM/EDS



NJNEHIN1-Pb

SEM/EDS




Newark, NJ
Lead Service Line
Address: 85 Astor
Installed: ?
Removed: 23 May 2019

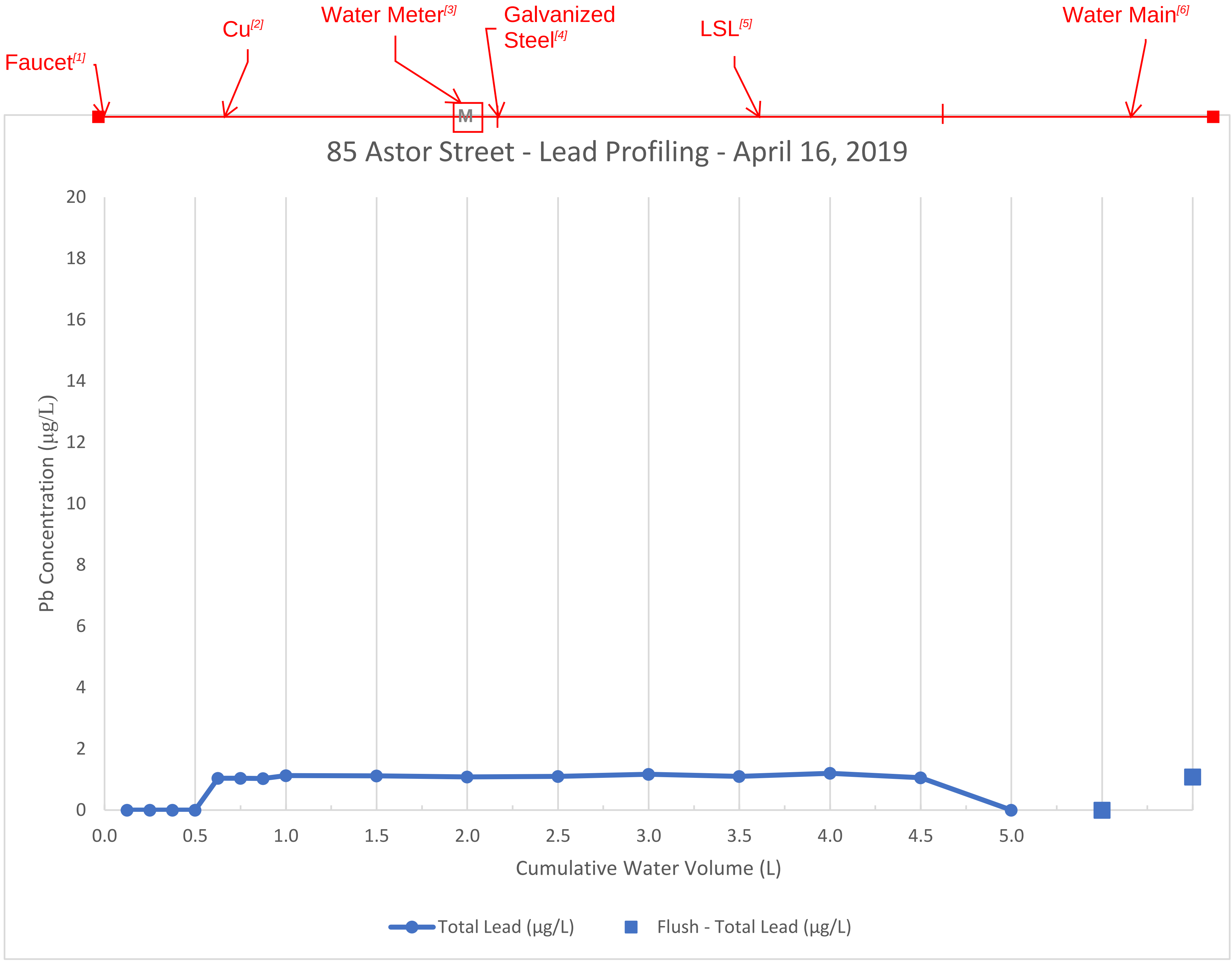

Faucet[1]
Cu[2]
Water Meter[3]
Galvanized Steel[4]
LSL[5]
Water Main[6]
M
85 Astor Street - Lead Profiling - April 16, 2019
Pb Concentration (µg/L)
20
18
16
14
12
10
8
6
4
2
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Cumulative Water Volume (L)
Total Lead (µg/L)
Flush - Total Lead (µg/L)

Table 1-1N
City of Newark Sequential Monitoring
Analytical Results
85 Astor St.

Site N - 4/16/19

Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters										Location/ Description
				pH[1]	Temp[1] (degrees C)	Free Cl_2[1] (mg/L)	Total Pb (μg/L)	Total Cu (mg/L)	Alkalinity (mg/L as $CaCO_3$)	TAC (DW)	Anions (Sulfate, Chloride, Fluoride)	Orthophosphate (mg/L as P)	Silica (mg/L as SiO2)	
N-0	500	N/A	Field Blank				0.00	0.00						Field Blank - Newark to Provide Type 1 Water
N-1	125	125	After Stagnation				0.00	19.90						Copper Piping (100%)
N-2	125	250	After Stagnation				0.00	4.17						Copper Piping (100%)
N-3	125	375	After Stagnation				0.00	3.50						Copper Piping (100%)
N-4	125	500	After Stagnation				0.00	2.88						Copper Piping (100%)
N-5	125	625	After Stagnation				1.04	2.50						Copper Piping (100%)
N-6	125	750	After Stagnation				1.04	2.09						Copper Piping (100%)
N-7	125	875	After Stagnation				1.03	1.83						Copper Piping (100%)
N-8	125	1000	After Stagnation				1.13	2.41						Copper Piping (100%)
N-9	500	1500	After Stagnation	7.8	13.8	0.93	1.12	1.78	27.20			0.52		Copper Piping (100%)
N-10	500	2000	After Stagnation				1.08	2.57						Copper Piping (100%)
N-11	500	2500	After Stagnation				1.10	2.27						Copper Piping (8%); Galvanized Piping (18%); Lead Piping (74%)
N-12	500	3000	After Stagnation				1.17	2.52						Lead Piping (100%)
N-13	500	3500	After Stagnation				1.10	2.27						Lead Piping (100%)
N-14	500	4000	After Stagnation				1.20	1.95						Lead Piping (100%)
N-15	500	4500	After Stagnation				1.06	1.83						Lead Piping (100%)
N-16	500	5000	After Stagnation				0.00	1.89						Lead Piping (13%); Water Main (87%)
N-17	500	5500	Flushed after the sequential sampling				0.00	1.74		See Table Below				Water Main (100%)
N-18	500	6000	Flushed after the sequential sampling				1.08	1.67			See Table Below			Water Main (100%)
N-19	500	6500	Flushed after the sequential sampling	7.78	13.6	0.89			24.60			0.52		Water Main (100%)

NOTES

1. pH, temperature, and free and total chlorine will be field measured.
2. **HOMEOWNER SHOULD FLUSH THE LINE FOR 10 MINUTES BEFORE BEGINNING STAGNATION PERIOD (i.e. night before sampling).**

Table 1-1N
City of Newark Sequential Monitoring
Analytical Results
85 Astor St.

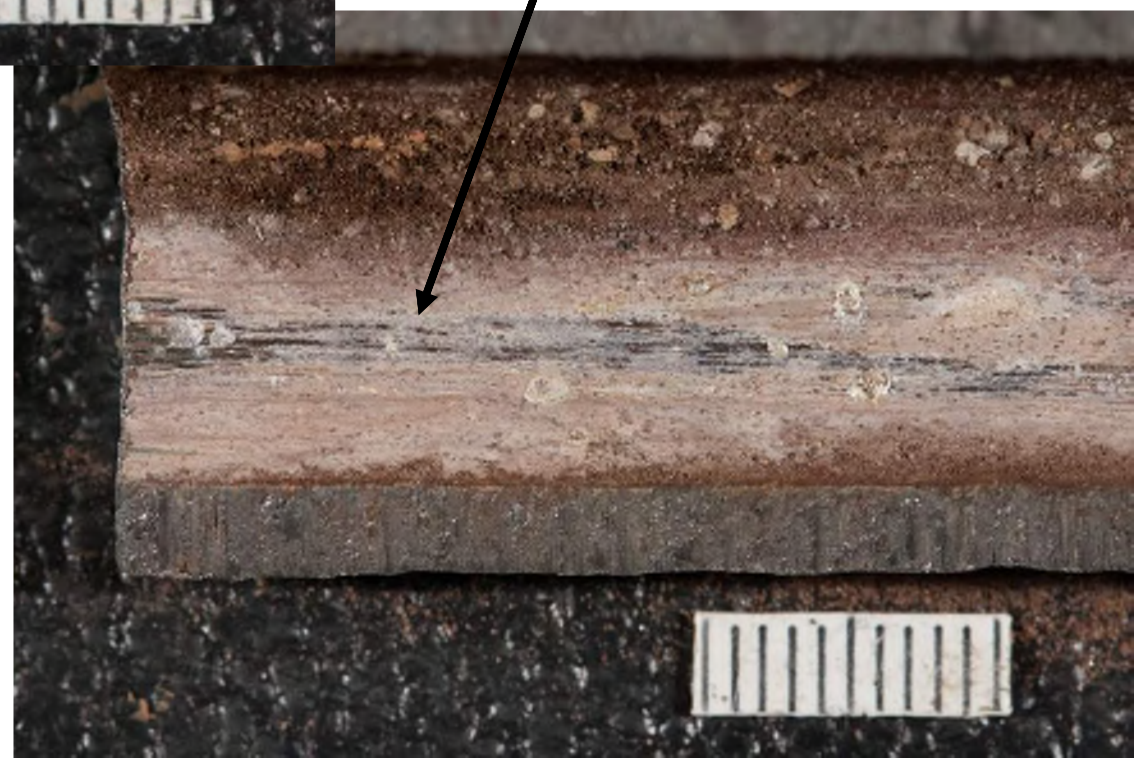
Site N - 4/16/19

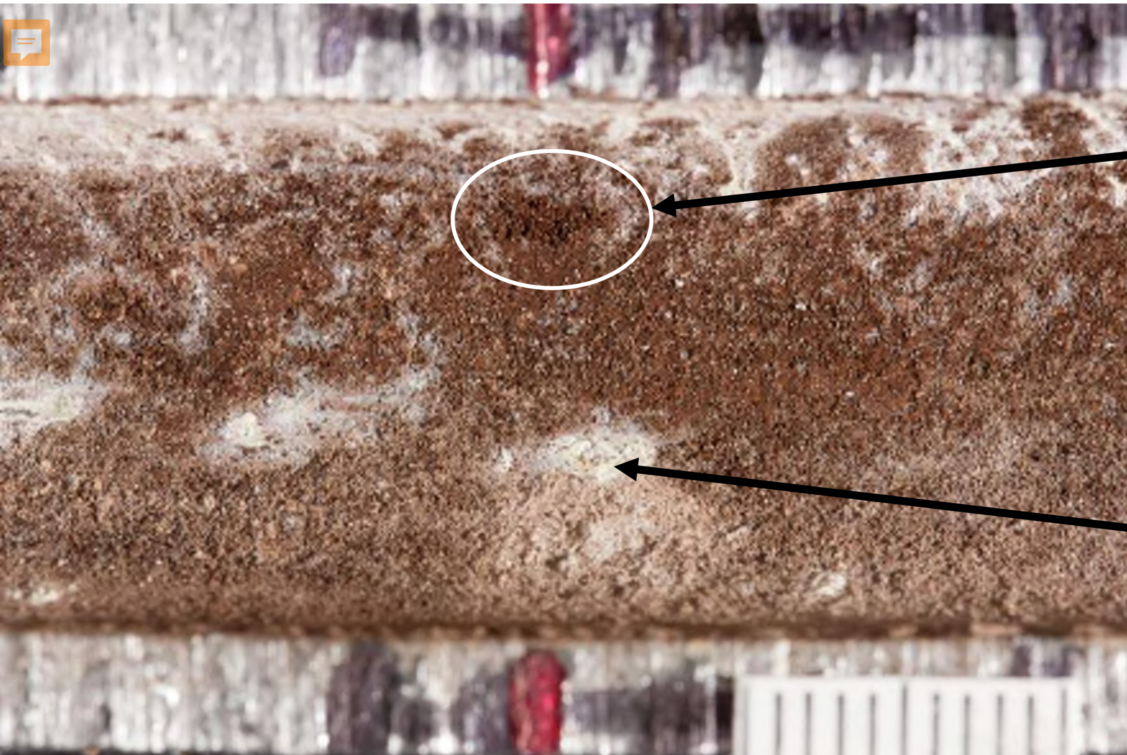
Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters										Location/ Description
				pH[1]	Temp[1] (degrees C)	Free Cl_2[1] (mg/L)	Total Pb (µg/L)	Total Cu (mg/L)	Alkalinity (mg/L as $CaCO_3$)	TAC (DW)	Anions (Sulfate, Chloride, Fluoride)	Orthophosphate (mg/L as P)	Silica (mg/L as SiO2)	

P-31 TAC (DW)		Units
Calcium	10700	µg/L
Iron	0	µg/L
Magnesium	2850	µg/L
Potassium	818	µg/L
Sodium	24500	µg/L
Aluminum	45.1	µg/L
Antimony	0	µg/L
Arsenic	0	µg/L
Barium	7.06	µg/L
Beryllium	0	µg/L
Cadmium	0	µg/L
Chromium	0	µg/L
Cobalt	0	µg/L
Manganese	3.89	µg/L
Molybdenum	0	µg/L
Nickel	0	µg/L
Selenium	0	µg/L
Silver	0	µg/L
Thallium	0	µg/L
Vanadium	0	µg/L
Zinc	2.81	µg/L

P-32 Anions		Units
Chloride	48	mg/L
Fluoride	0	mg/L
Sulfate	6.8	mg/L

Gouges from cable tool extraction of LSL

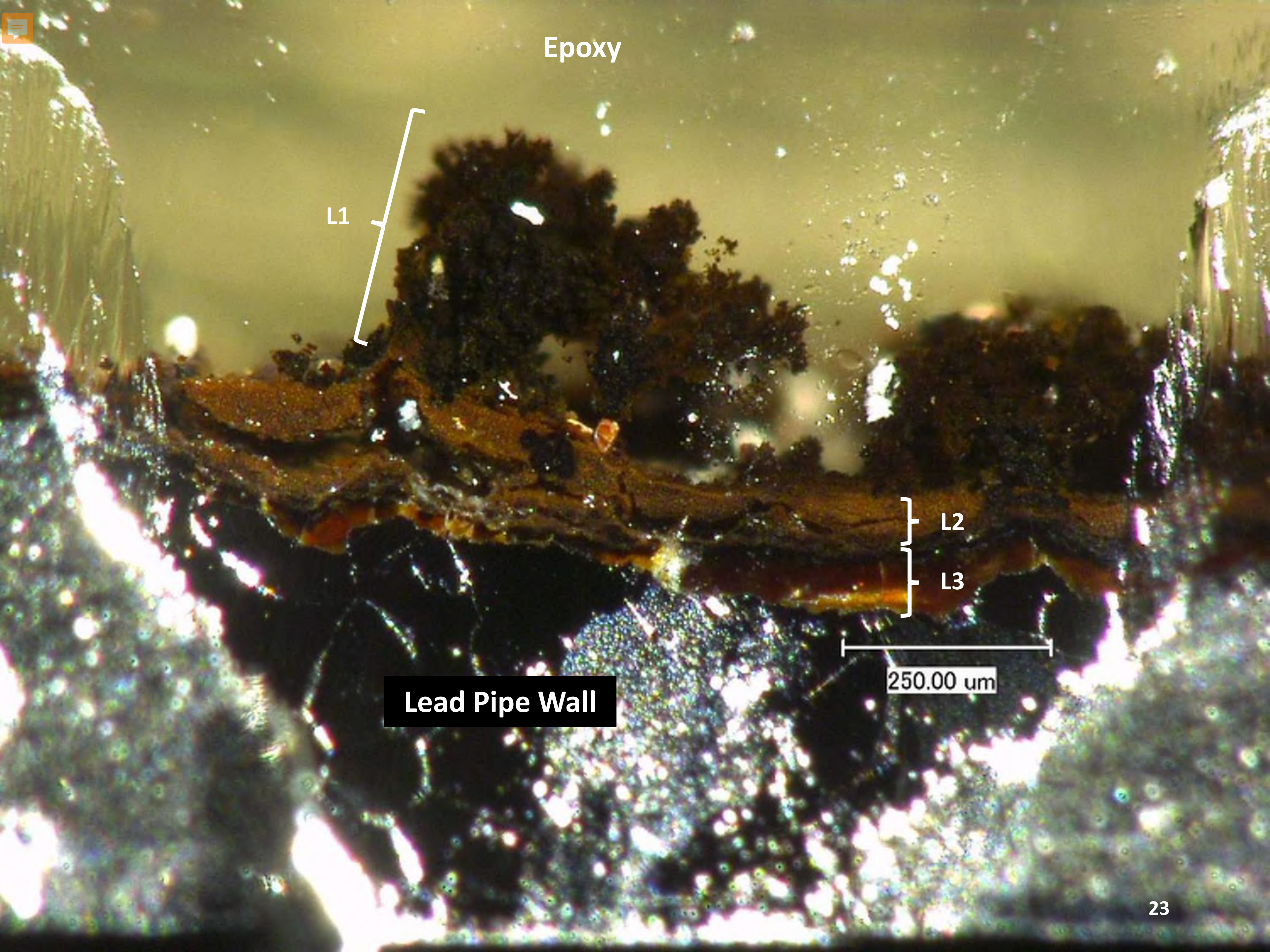


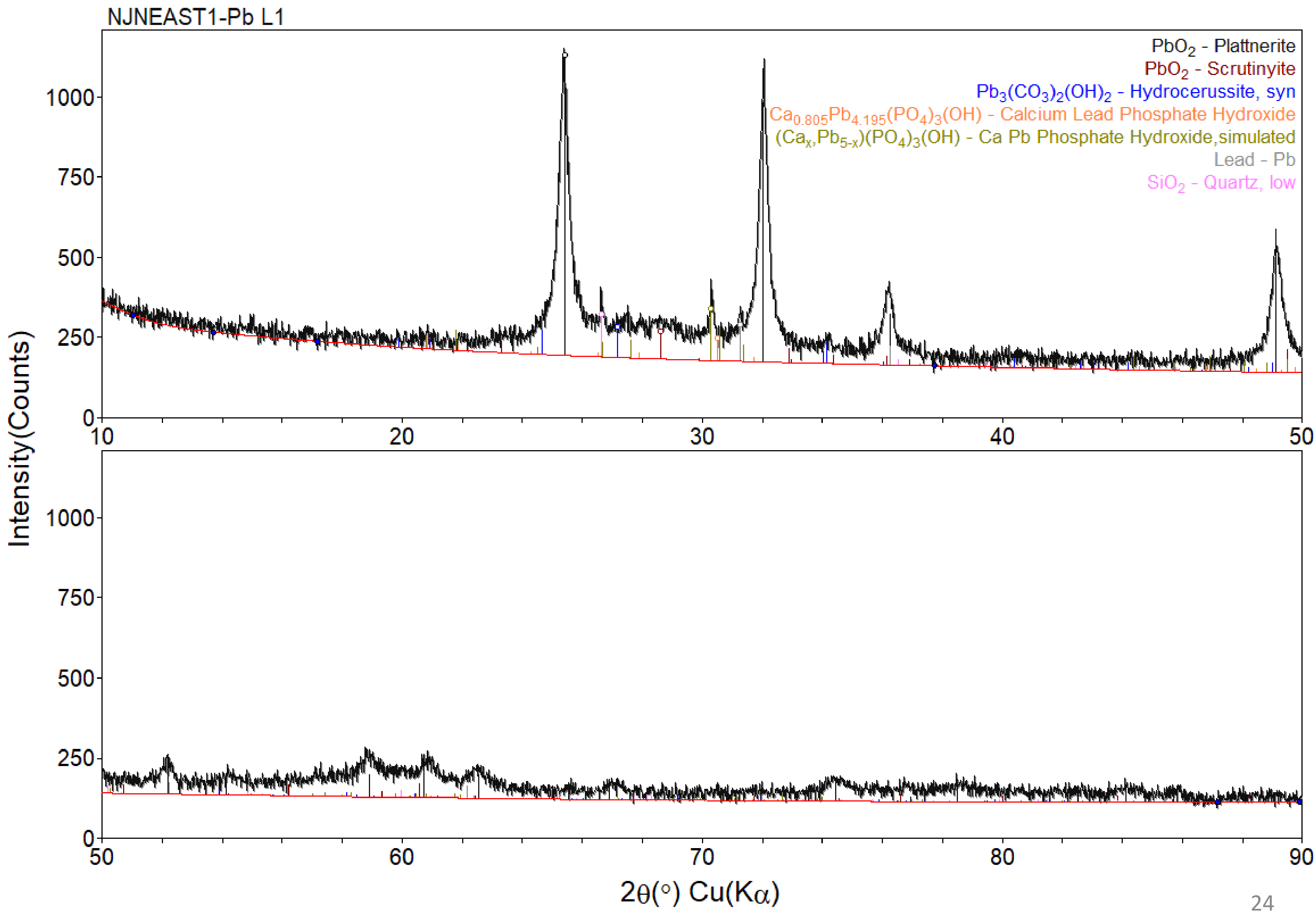


Area of intact scale, cross-sectioned and analyzed with SEM/EDS.

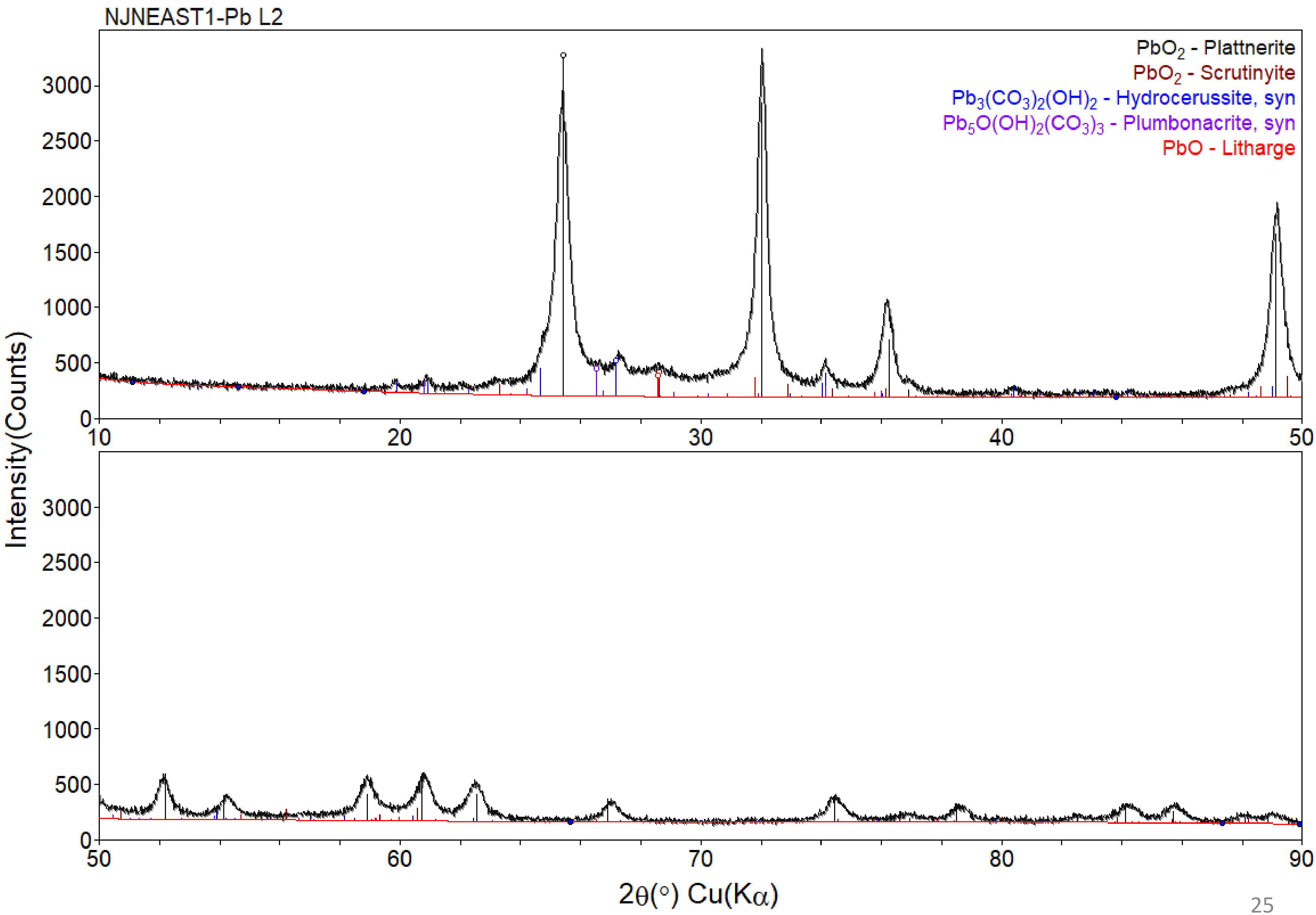
Pinkish white material ('nacreous layer'), secondarily formed over areas disrupted by cable tool.

Area of scale harvested and analyzed by XRD (slightly disrupted layer L1 visible here, layers L2 and L3 not visible).

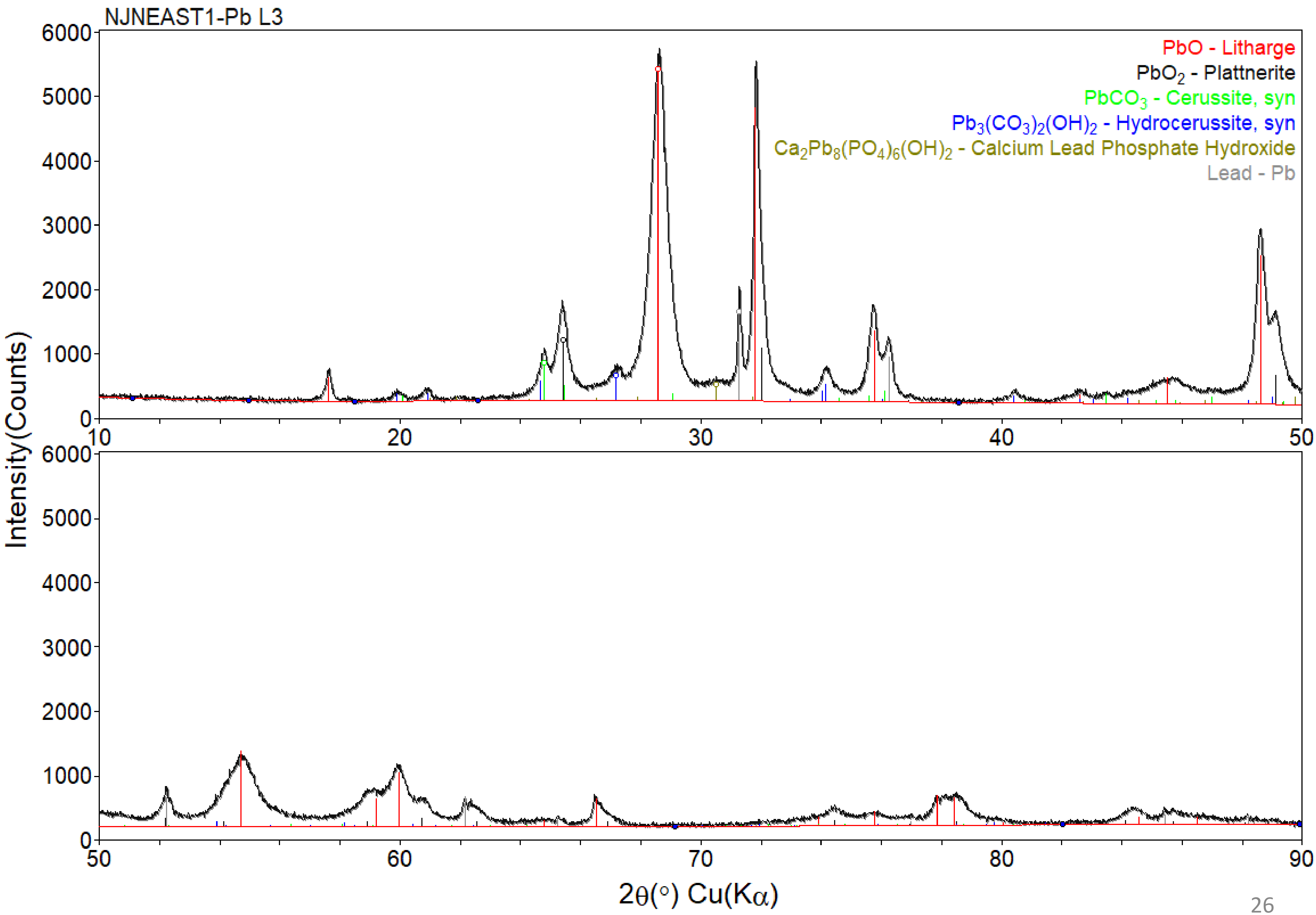

Epoxy
L1
L2
L3
250.00 um
Lead Pipe Wall

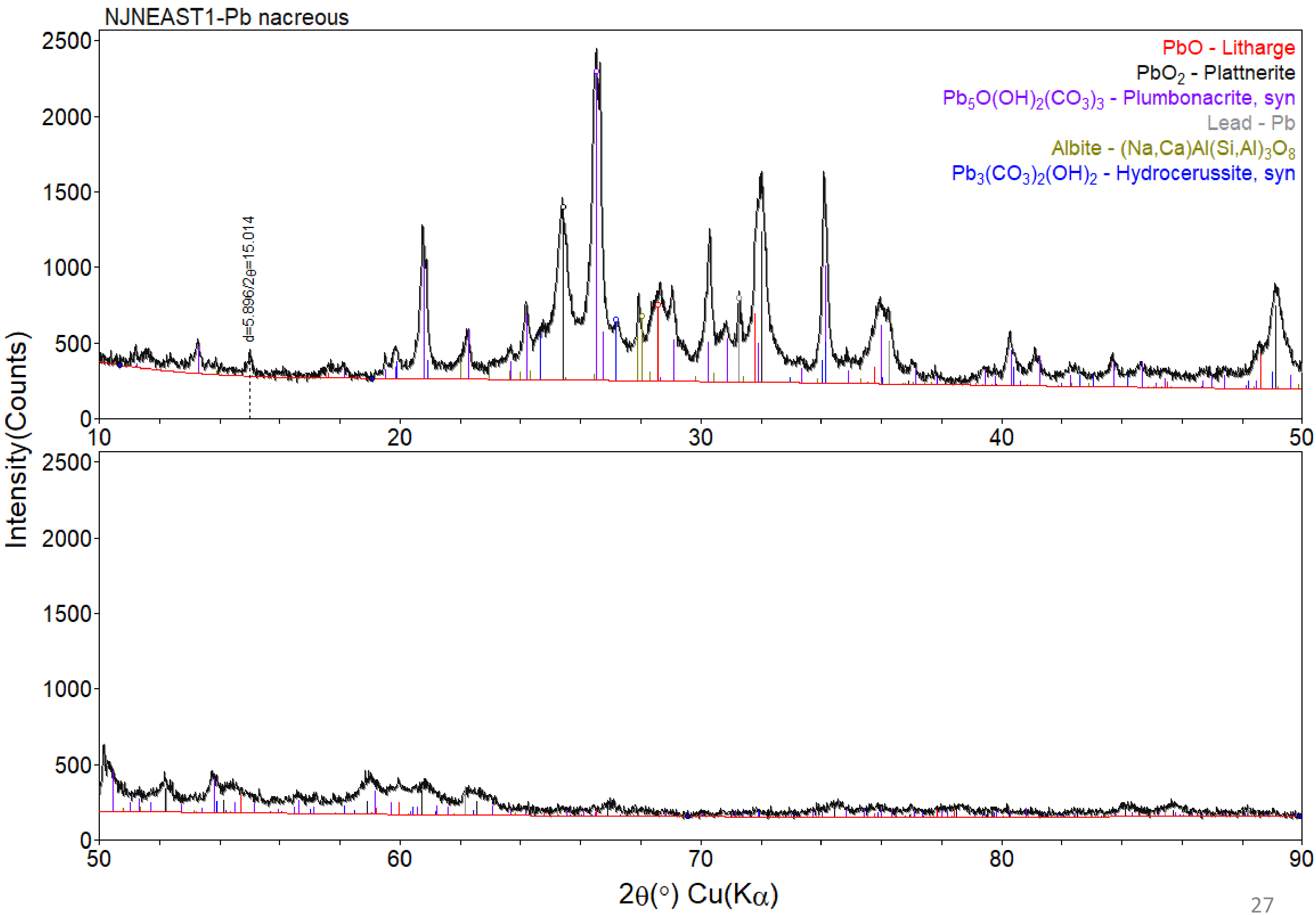


NJNEAST1-Pb L1
PbO2 - Plattnerite
PbO2 - Scrutinyite
Pb3(CO3)2(OH)2 - Hydrocerussite, syn
Ca0.805Pb4.195(PO4)3(OH) - Calcium Lead Phosphate Hydroxide
(Cax,Pb5-x)(PO4)3(OH) - Ca Pb Phosphate Hydroxide,simulated
Lead - Pb
SiO2 - Quartz, low
Intensity(Counts)
2θ(°) Cu(Kα)

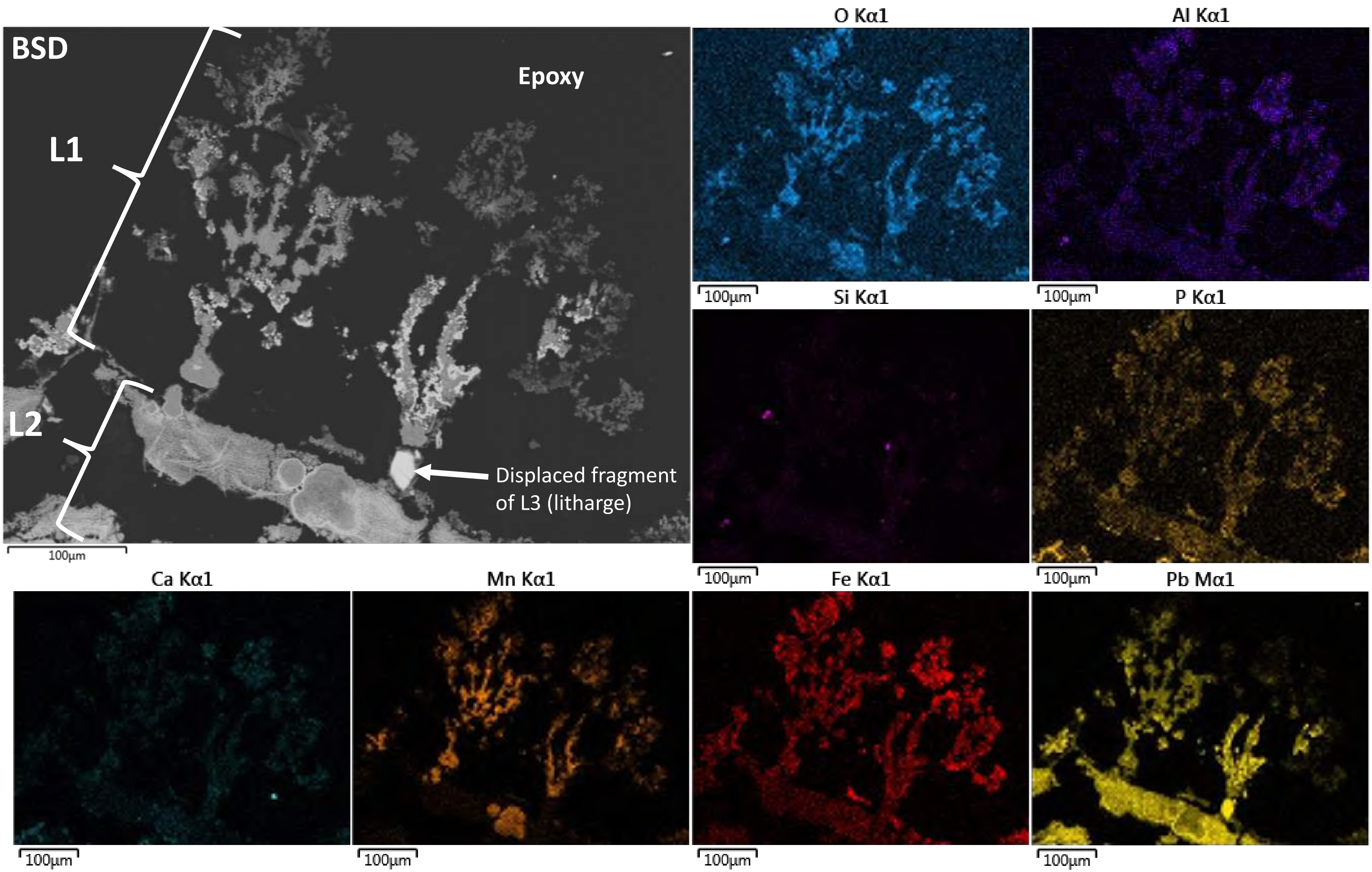


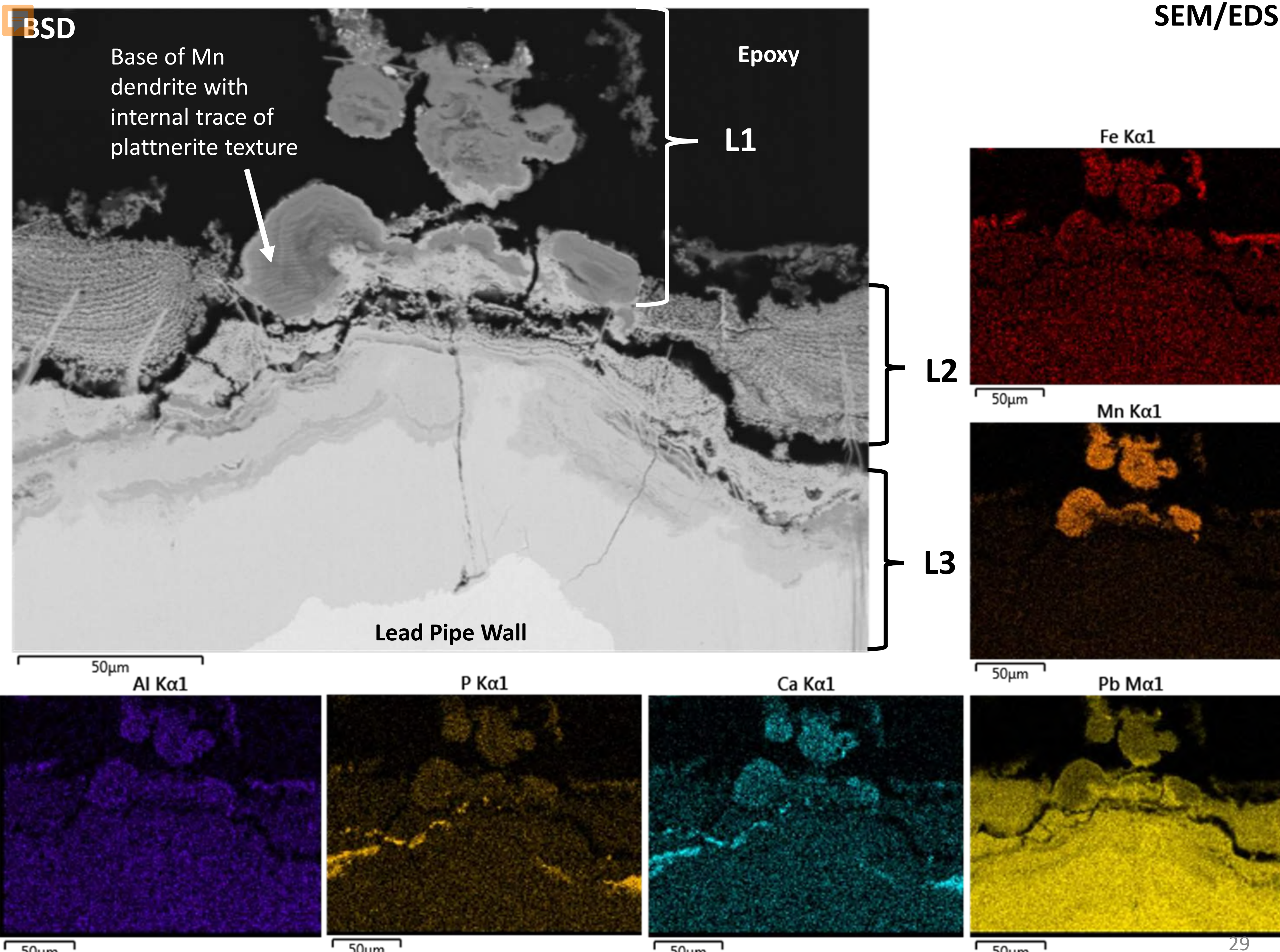
NJNEAST1-Pb L2
PbO2 - Plattnerite
PbO2 - Scrutinyite
Pb3(CO3)2(OH)2 - Hydrocerussite, syn
Pb5O(OH)2(CO3)3 - Plumbonacrite, syn
PbO - Litharge
Intensity(Counts)
3000
2500
2000
1500
1000
500
0
10
20
30
40
50
60
70
80
90
2θ(°) Cu(Kα)


NJNEAST1-Pb L3
PbO - Litharge
PbO_2 - Plattnerite
$PbCO_3$ - Cerussite, syn
$Pb_3(CO_3)_2(OH)_2$ - Hydrocerussite, syn
$Ca_2Pb_8(PO_4)_6(OH)_2$ - Calcium Lead Phosphate Hydroxide
Lead - Pb
Intensity(Counts)
2θ(°) Cu(Kα)
0
1000
2000
3000
4000
5000
6000
10
20
30
40
50
60
70
80
90


NJNEAST1-Pb nacreous
PbO - Litharge
PbO2 - Plattnerite
Pb5O(OH)2(CO3)3 - Plumbonacrite, syn
Lead - Pb
Albite - (Na,Ca)Al(Si,Al)3O8
Pb3(CO3)2(OH)2 - Hydrocerussite, syn
d=5.896/2θ=15.014
Intensity(Counts)
2θ(°) Cu(Kα)

SEM/EDS


BSD
Epoxy
L1
L2
Displaced fragment of L3 (litharge)
100µm
O Kα1
Al Kα1
Si Kα1
P Kα1
Ca Kα1
Mn Kα1
Fe Kα1
Pb Mα1


BSD
Base of Mn dendrite with internal trace of plattnerite texture
Epoxy
L1
L2
L3
Lead Pipe Wall
50μm
Fe Kα1
50μm
Mn Kα1
50μm
Al Kα1
50μm
P Kα1
50μm
Ca Kα1
50μm
Pb Mα1
50μm

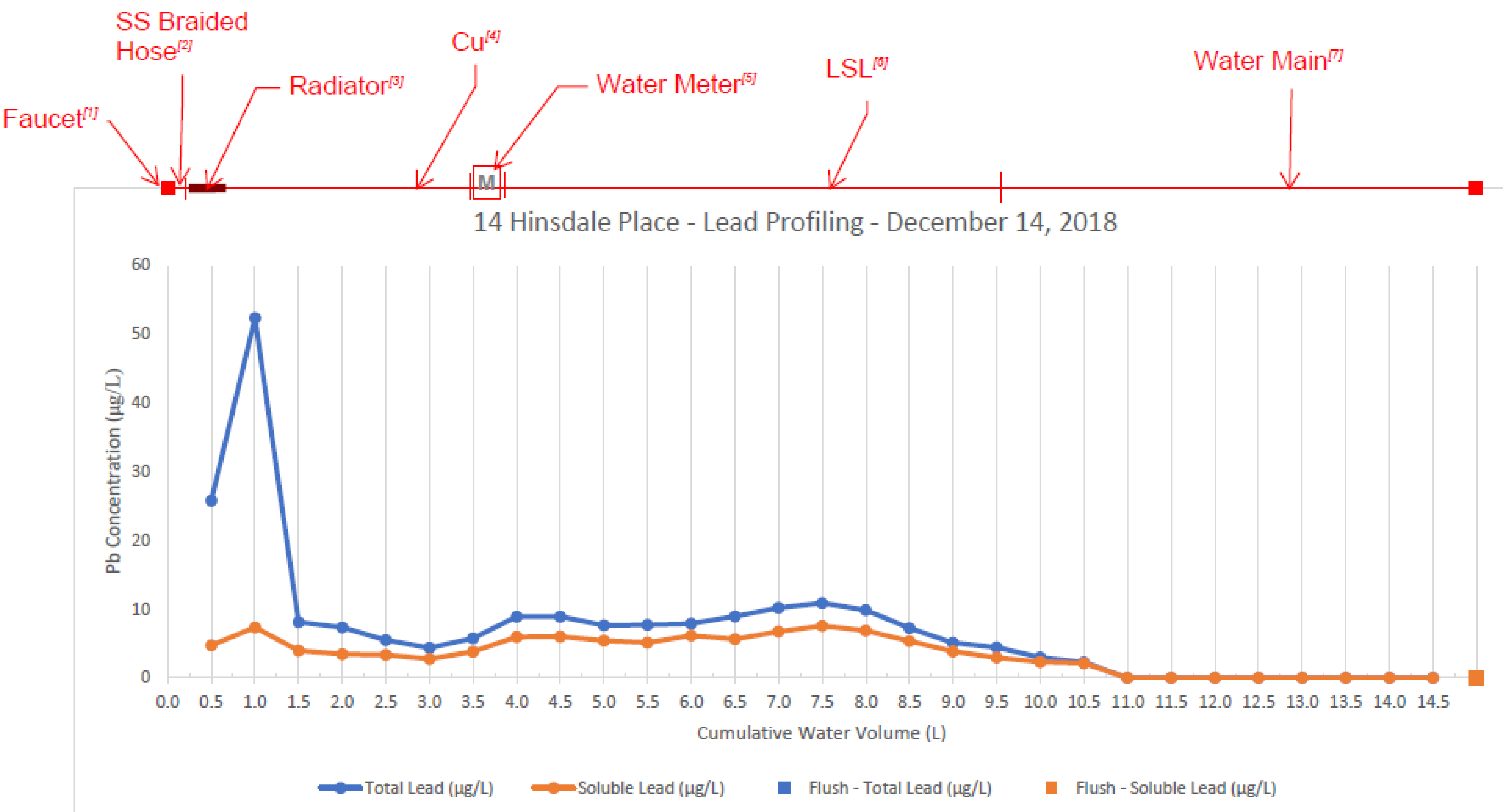
Newark, NJ

LSL samples extracted December 20, 2018

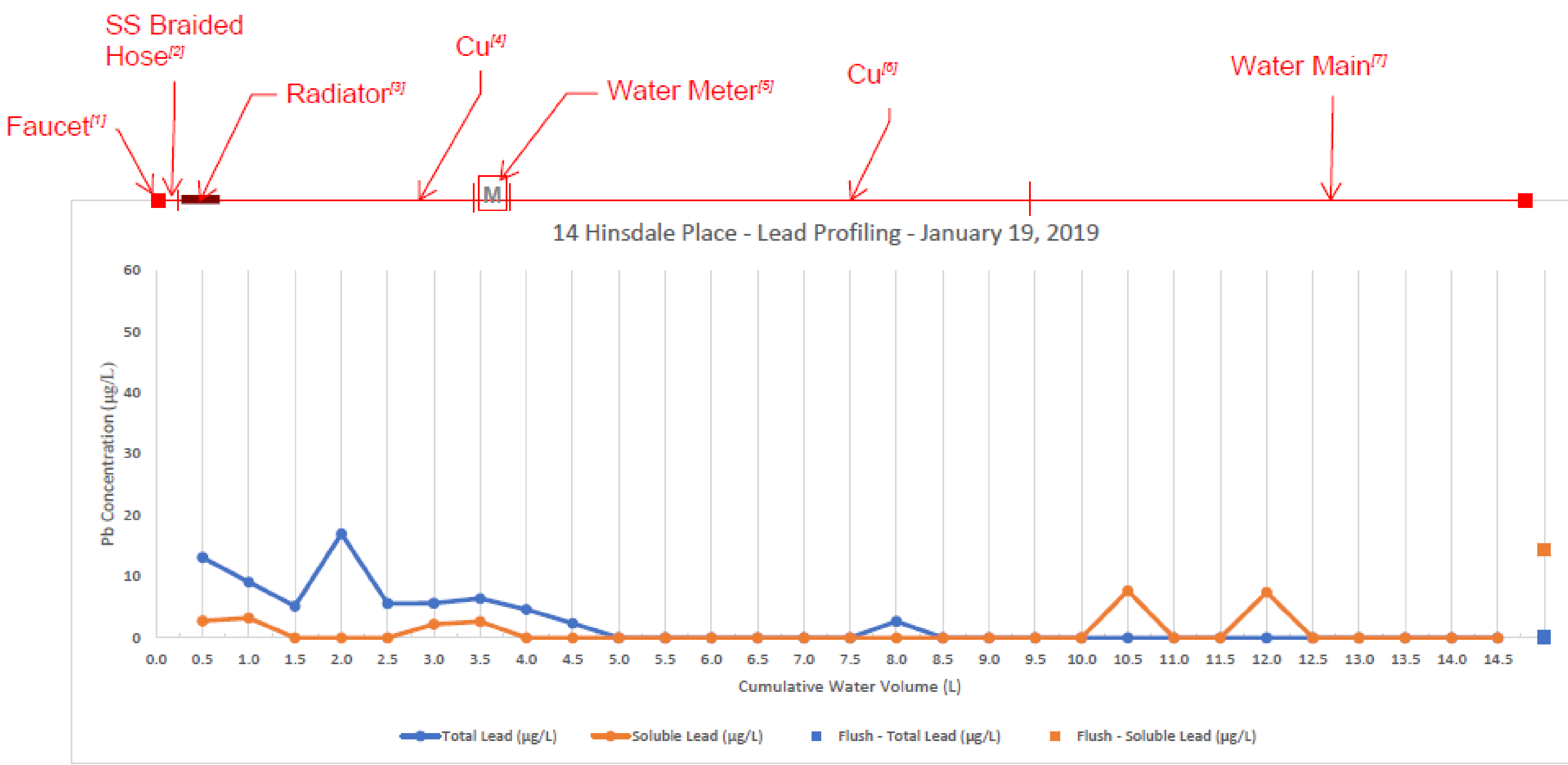
Report from:

Advanced Materials and Solids Analysis Research Core

Cincinnati, OH

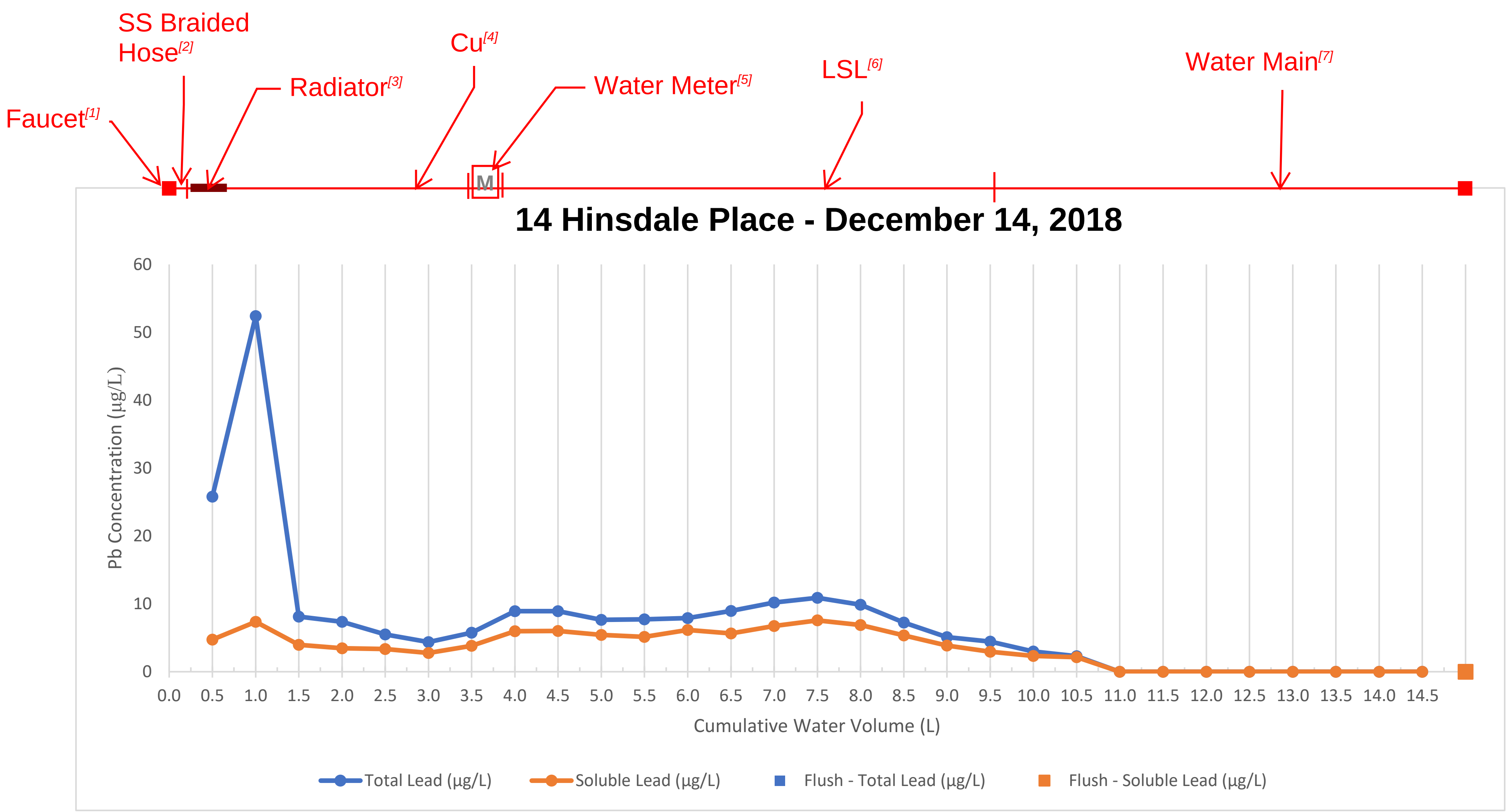


Before LSL replacement



After LSL replacement


Newark, NJ
Lead Service Line
Address: 14 Hinsdale Pl.
Installed: 1910
Removed: December 20, 2018



SS Braided Hose[2]
Cu[4]
LSL[6]
Water Main[7]
Radiator[3]
Water Meter[5]
Faucet[1]
M
14 Hinsdale Place - December 14, 2018
Pb Concentration (µg/L)
60
50
40
30
20
10
0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5 13.0 13.5 14.0 14.5
Cumulative Water Volume (L)
Total Lead (µg/L)
Soluble Lead (µg/L)
Flush - Total Lead (µg/L)
Flush - Soluble Lead (µg/L)

Table 1-1C
City of Newark Sequential Monitoring
Analytical Results
14 Hinsdale

Site C - 12/14/18

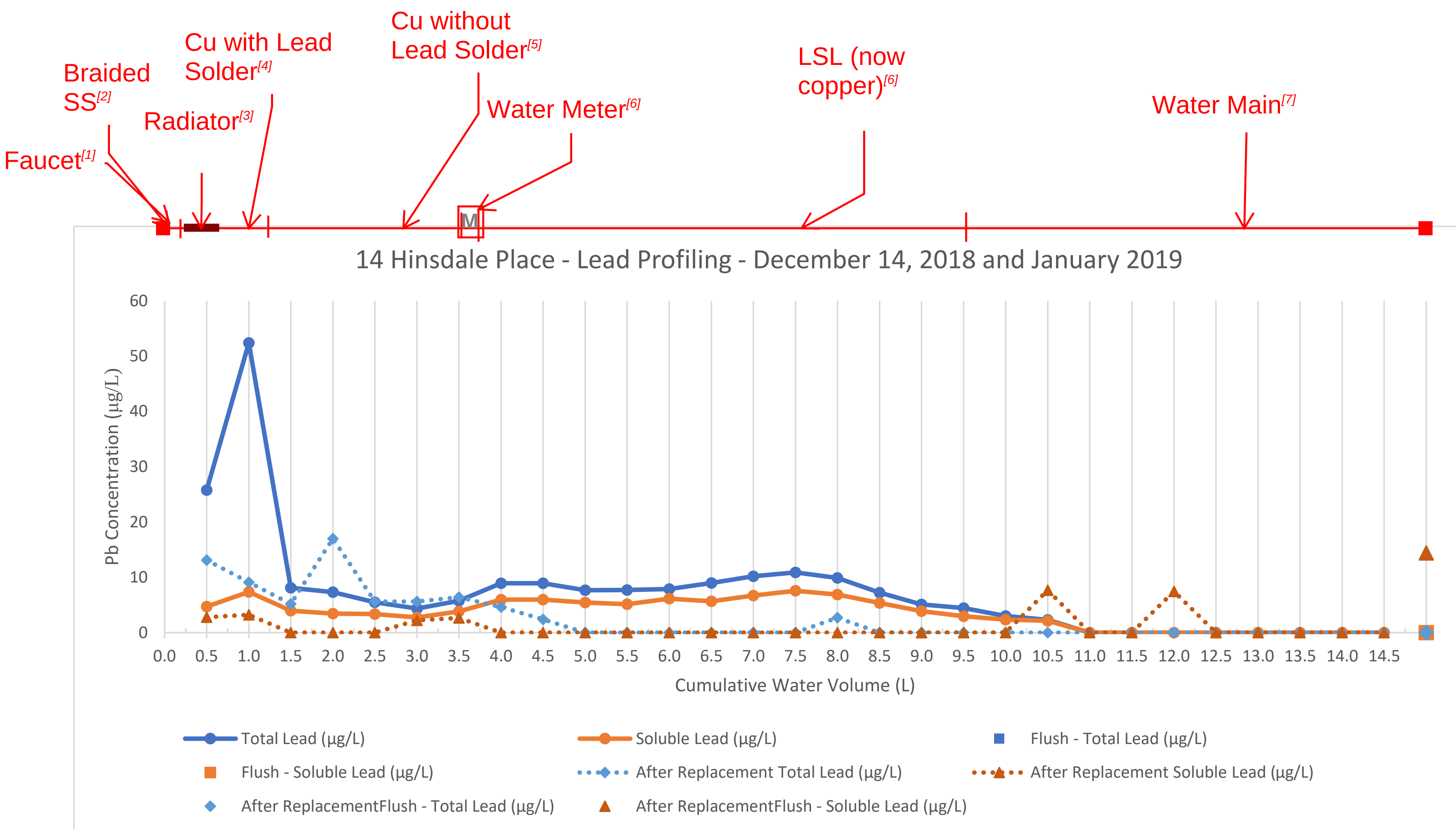
Sample	Volume	Cumulative Volume	Collection	Water Quality Parameters										Location/ Description
	(mL)	(mL)		pH[1]	Temp[1]	Free Cl_2[1]	Total Pb	Dissolved Pb	Total Cu	Alk.	Cond.	Othophosphate	Silica	
					(degrees C)	(mg/L)	(µg/L)	(µg/L)	(mg/L)	(mg/L as $CaCO_3$)	umhos/cm	(mg/L as P)	(mg/L as SiO2)	
C1	500	500	After Stagnation	N/A	N/A	N/A	25.8	4.72	0.26	42.0	225	<.100		Faucet (13% SS Flex) and Copper Piping with Lead Solder (87%)
C2	500	1000	After Stagnation				52.4	7.35	0.296			<.100	6.41	Copper Piping with Lead Solder (100%)
C3	500	1500	After Stagnation				8.11	3.95	0.182			<.100		Copper Piping with Lead Solder (100%)
C4	500	2000	After Stagnation				7.34	3.44	0.187			<.100		Copper Piping with Lead Solder (100%)
C5	500	2500	After Stagnation				5.49	3.34	0.17			<.100		Copper Piping with Lead Solder (100%)
C6	500	3000	After Stagnation				4.37	2.75	0.149			<.100		Copper Piping with Lead Solder (100%)
C7	500	3500	After Stagnation				5.75	3.83	0.12			<.100		Copper Piping with Lead Solder (100%)
C8	500	4000	After Stagnation				8.91	5.96	0.0692			<.100		Copper Piping (100%); Lead Piping (70%)
C9	500	4500	After Stagnation				8.91	5.99	<.05			<.100		Lead Piping (100%)
C10	500	5000	After Stagnation				7.65	5.44	<.05			<.100		Lead Piping (100%)
C11	500	5500	After Stagnation				7.73	5.13	<.05			<.100		Lead Piping (100%)
C12	500	6000	After Stagnation				7.9	6.16	<.05			<.100		Lead Piping (100%)
C13	500	6500	After Stagnation				8.97	5.66	<.05			<.100		Lead Piping (100%)
C14	500	7000	After Stagnation				10.2	6.73	<.05			<.100		Lead Piping (100%)
C15	500	7500	After Stagnation				10.9	7.56	<.05			<.100		Lead Piping (100%)
C16	500	8000	After Stagnation	N/A	N/A	N/A	9.88	6.87	<.05			<.100		Lead Piping (100%)
C17	500	8500	After Stagnation				7.23	5.36	<.05	28.0	210	<.100	6.48	Lead Piping (100%)
C18	500	9000	After Stagnation				5.08	3.87	<.05			<.100		Lead Piping (100%)
C19	500	9500	After Stagnation				4.43	2.96	<.05			<.100		Lead Piping (100%)
C20	500	10000	After Stagnation				3.00	2.34	<.05			<.100		Lead Piping (11%); Water Main (89%)
C21	500	10500	After Stagnation				2.30	2.15	<.05			<.100		Water Main (100%)
C22	500	11000	After Stagnation				2.04	<2.00	<.05			<.100		Water Main (100%)
C23	500	11500	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)
C24	500	12000	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)
C25	500	12500	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)
C26	500	13000	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)
C27	500	13500	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)

Table 1-1C
City of Newark Sequential Monitoring
Analytical Results
14 Hinsdale

Site C - 12/14/18

Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters										Location/ Description
				pH[1]	Temp[1]	Free Cl_2[1]	Total Pb	Dissolved Pb	Total Cu	Alk.	Cond.	Othophosphate	Silica	
					(degrees C)	(mg/L)	(µg/L)	(µg/L)	(mg/L)	(mg/L as $CaCO_3$)	umhos/cm	(mg/L as P)	(mg/L as SiO2)	
C28	500	14000	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)
C29	500	14500	After Stagnation				<2.00	<2.00	<.05			<.100		Water Main (100%)
C30FLUSH	500	15000	Flushed after the sequential sampling	N/A	N/A	N/A	<2.00	<2.00	<.05	28.0	214	<.100	6.57	Water Main (100%)

NOTES
1. pH, temperature, and free and total chlorine will be field measured.
2. **HOMEOWNER SHOULD FLUSH THE LINE FOR 10 MINUTES BEFORE BEGINNING STAGNATION PERIOD (i.e. night before sampling). TIME OF FLUSH / START OF STAGNATION PERIOD SHOULD BE RECORDED**



Braided SS[2]
Cu with Lead Solder[4]
Cu without Lead Solder[5]
LSL (now copper)[6]
Radiator[3]
Water Meter[6]
Water Main[7]
Faucet[1]
M
14 Hinsdale Place - Lead Profiling - December 14, 2018 and January 2019
Pb Concentration (µg/L)
60
50
40
30
20
10
0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5 13.0 13.5 14.0 14.5
Cumulative Water Volume (L)
Total Lead (µg/L)
Soluble Lead (µg/L)
Flush - Total Lead (µg/L)
Flush - Soluble Lead (µg/L)
After Replacement Total Lead (µg/L)
After Replacement Soluble Lead (µg/L)
After ReplacementFlush - Total Lead (µg/L)
After ReplacementFlush - Soluble Lead (µg/L)

Table 1-1K
City of Newark Sequential Monitoring
Analytical Results
14 Hinsdale
After Lead Service Line Replacement

Site K - 1/19/19

Sample	Volume (mL)	Cumulative Volume (mL)	Collection	pH[1]	Temp[1] (degrees C)	Free Cl_2[1] (mg/L)	Total Pb (µg/L)	Dissolved Pb (µg/L)	Total Cu (mg/L)	Alk. (mg/L as $CaCO_3$)	Cond. umhos/cm	Othophosphate (mg/L as P)	Silica (mg/L as SiO2)	Location/ Description
K1	500	500	After Stagnation	6.76	15.1	0.06	13.1	2.78	0.586	27.0	214			Faucet (13% SS Flex) and Copper Piping with Lead Solder (87%)
K2	500	1000	After Stagnation				9.11	3.23	0.531			<.1		Copper Piping with Lead Solder (100%)
K3	500	1500	After Stagnation				5.18	<2	0.522					Copper Piping with Lead Solder (100%)
K4	500	2000	After Stagnation				17	<2	0.59					Copper Piping with Lead Solder (100%)
K5	500	2500	After Stagnation				5.6	<2	0.556					Copper Piping with Lead Solder (100%)
K6	500	3000	After Stagnation				5.64	2.23	0.579					Copper Piping with Lead Solder (100%)
K7	500	3500	After Stagnation				6.39	2.67	0.664					Copper Piping with Lead Solder (100%)
K8	500	4000	After Stagnation				4.61	<2	1.22					Copper Piping (100%); Lead Piping (70%)
K9	500	4500	After Stagnation				2.38	<2	1.6					Lead Piping (100%)
K10	500	5000	After Stagnation				<2	<2	1.65					Lead Piping (100%)
K11	500	5500	After Stagnation				<2	<2	1.62					Lead Piping (100%)
K12	500	6000	After Stagnation				<2	<2	1.6					Lead Piping (100%)
K13	500	6500	After Stagnation				<2	<2	1.6					Lead Piping (100%)
K14	500	7000	After Stagnation				<2	<2	1.58					Lead Piping (100%)
K15	500	7500	After Stagnation				<2	<2	1.56					Lead Piping (100%)
K16	500	8000	After Stagnation	6.9	9.9	0.03	2.69	<2	1.48	31.0	202			Lead Piping (100%)
K17	500	8500	After Stagnation				<2	<2	1.53			<.1		Lead Piping (100%)
K18	500	9000	After Stagnation				<2	<2	1.51					Lead Piping (100%)
K19	500	9500	After Stagnation				<2	<2	1.46					Lead Piping (100%)
K20	500	10000	After Stagnation				<2	<2	1.19					Lead Piping (11%); Water Main (89%)
K21	500	10500	After Stagnation				<2	7.68	0.763					Water Main (100%)
K22	500	11000	After Stagnation				<2	<2	0.439					Water Main (100%)
K23	500	11500	After Stagnation				<2	<2	0.277					Water Main (100%)
K24	500	12000	After Stagnation				<2	7.44	0.192					Water Main (100%)
K25	500	12500	After Stagnation				<2	<2	0.15					Water Main (100%)
K26	500	13000	After Stagnation				<2	<2	0.131					Water Main (100%)
K27	500	13500	After Stagnation				<2	<2	0.127					Water Main (100%)

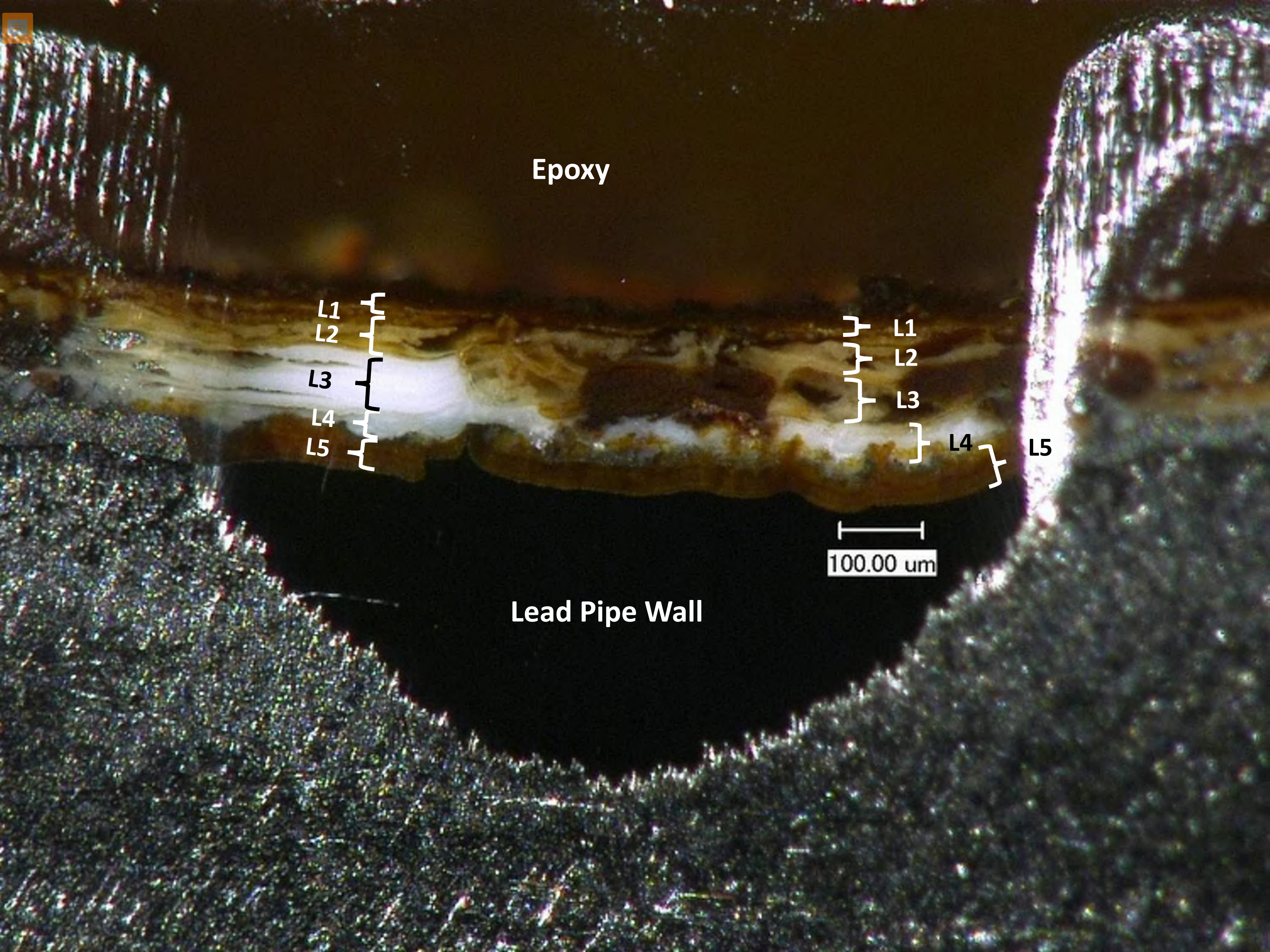
CDM Smith

Table 1-1K
City of Newark Sequential Monitoring
Analytical Results
14 Hinsdale
After Lead Service Line Replacement

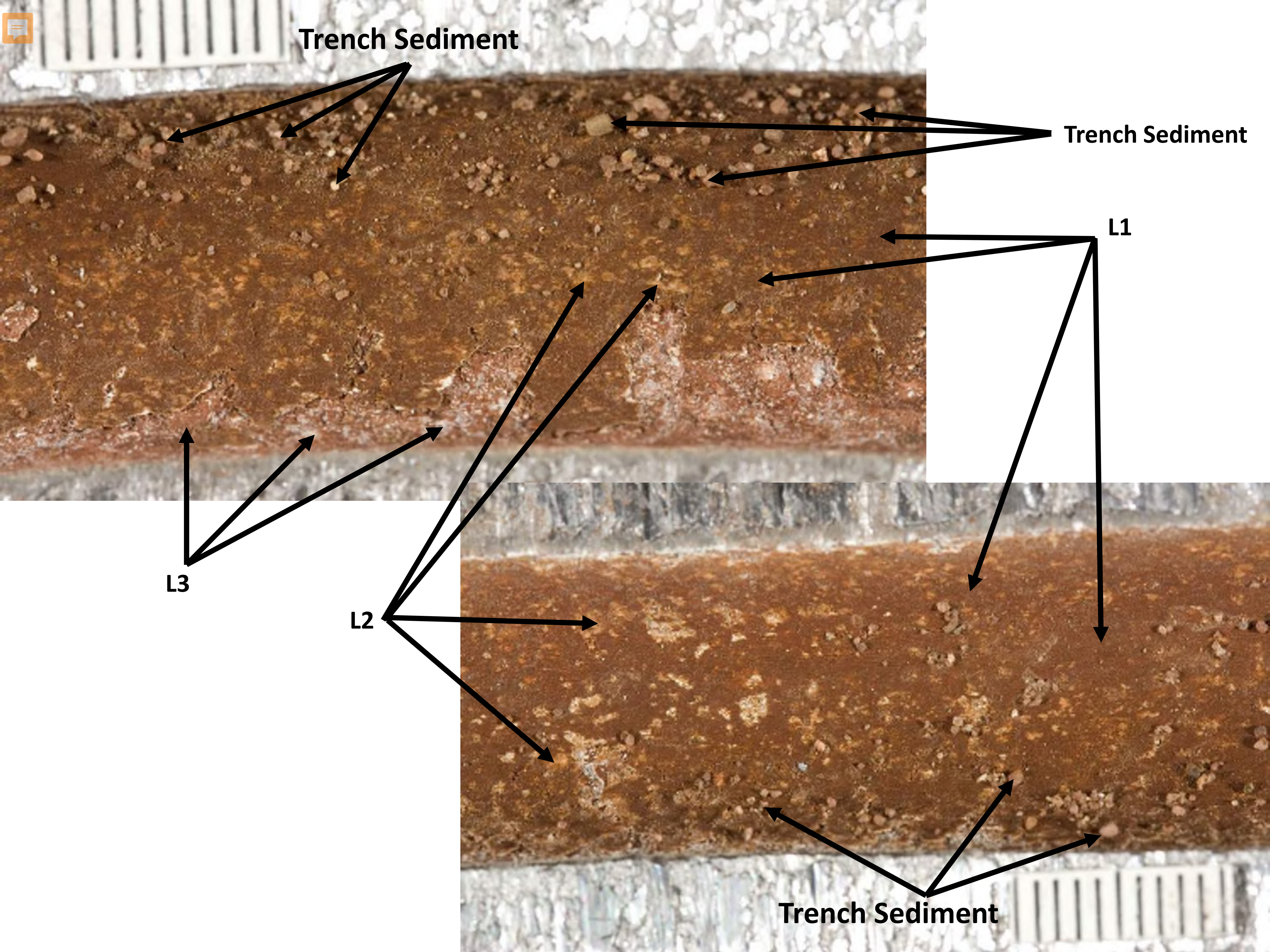
Site K - 1/19/19

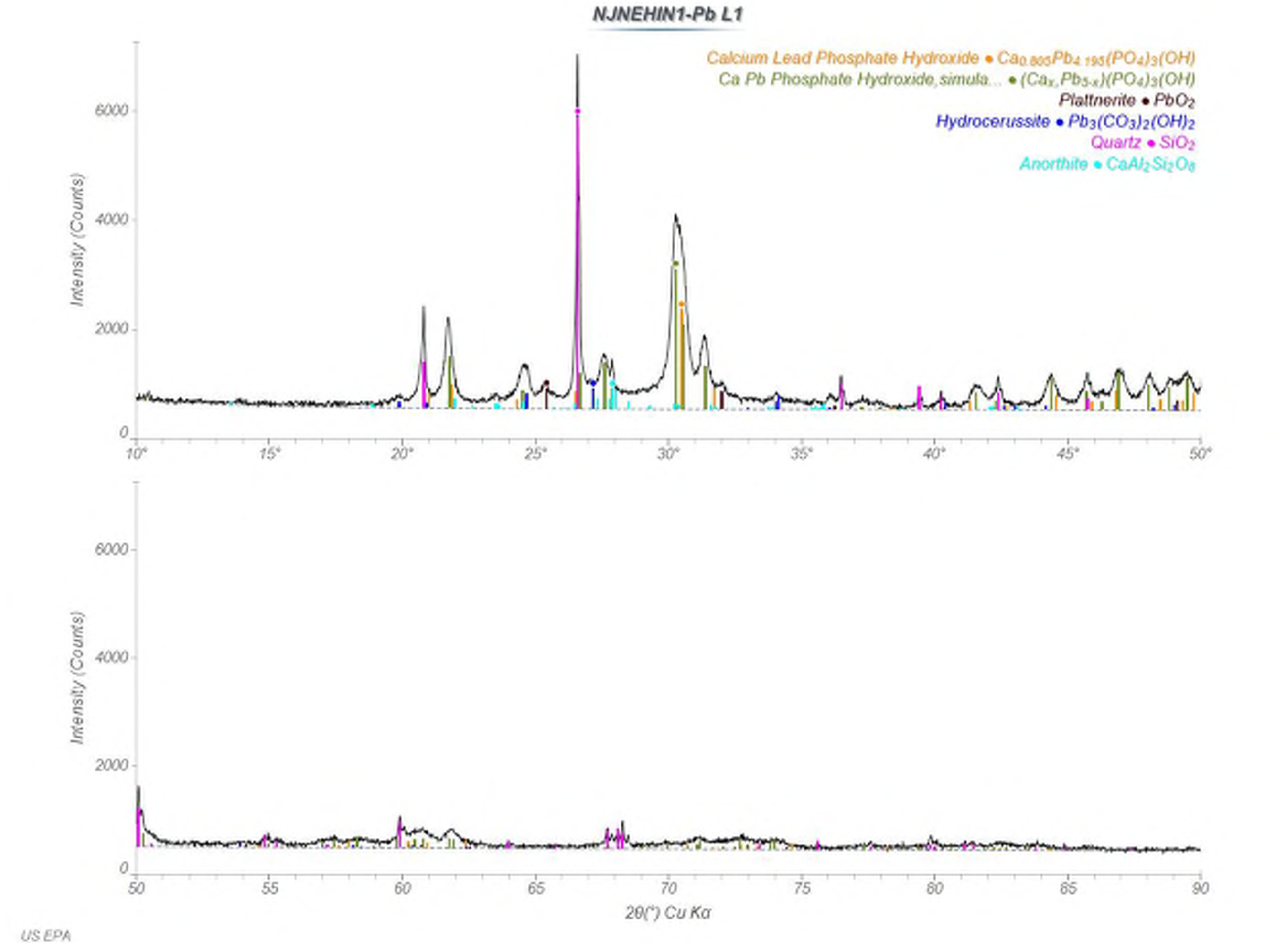
Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters										Location/ Description
				pH[1]	Temp[1]	Free Cl_2[1]	Total Pb	Dissolved Pb	Total Cu	Alk.	Cond.	Othophosphate	Silica	
					(degrees C)	(mg/L)	(µg/L)	(µg/L)	(mg/L)	(mg/L as $CaCO_3$)	umhos/cm	(mg/L as P)	(mg/L as SiO2)	
K28	500	14000	After Stagnation				<2	<2	0.113					Water Main (100%)
K29	500	14500	After Stagnation				<2	<2	0.11					Water Main (100%)
K30 FLUSH	500	15000	Flushed after the sequential sampling	6.82	8.9	0.98	<2	14.4	0.0646	30.0	211	0.702		Water Main (100%)

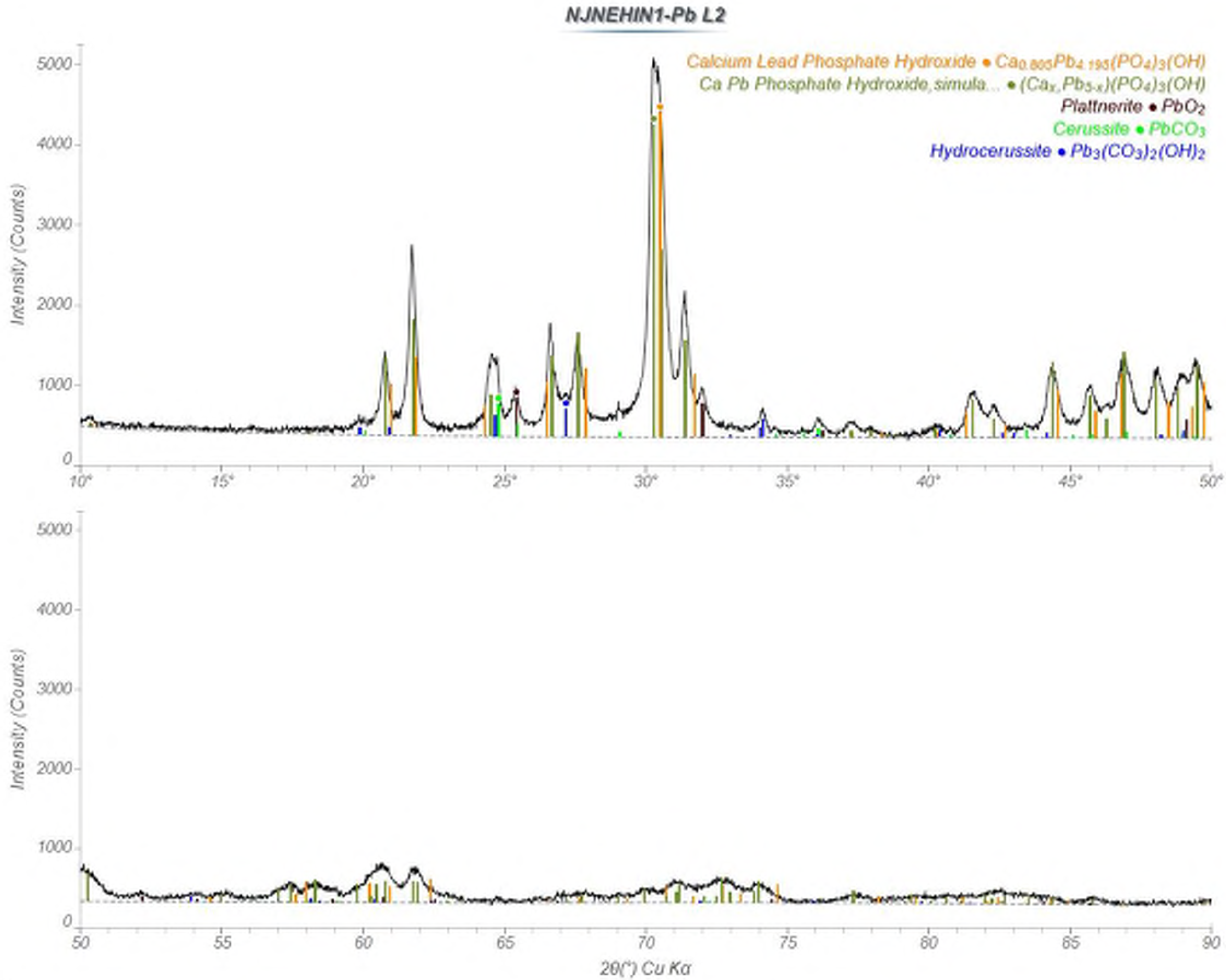
NOTES
1. pH, temperature, and free and total chlorine will be field measured.
2. **HOMEOWNER SHOULD FLUSH THE LINE FOR 10 MINUTES BEFORE BEGINNING STAGNATION PERIOD (i.e. night before sampling). TIME OF FLUSH / START OF STAGNATION PERIOD SHOULD BE RECORDED**

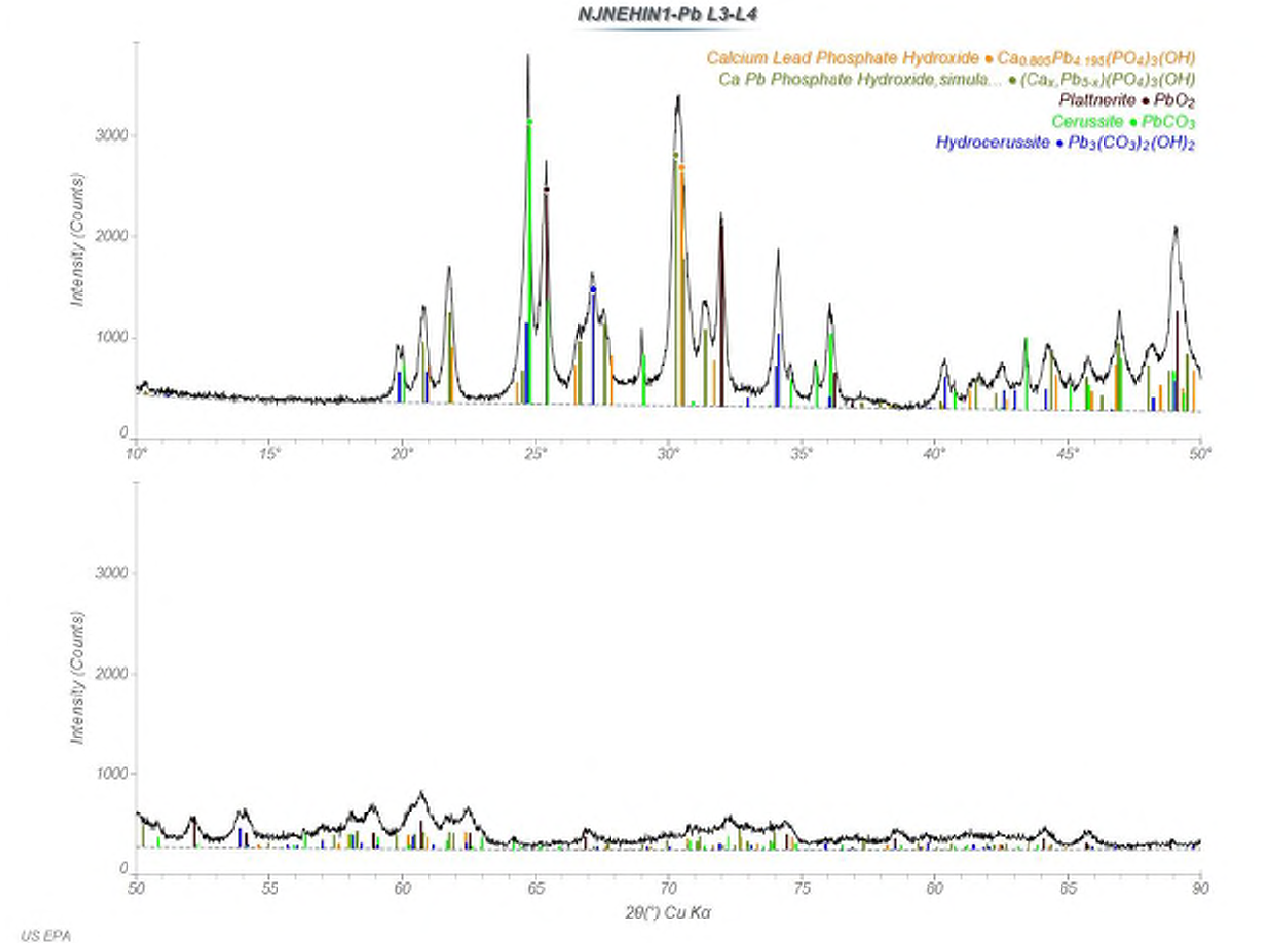


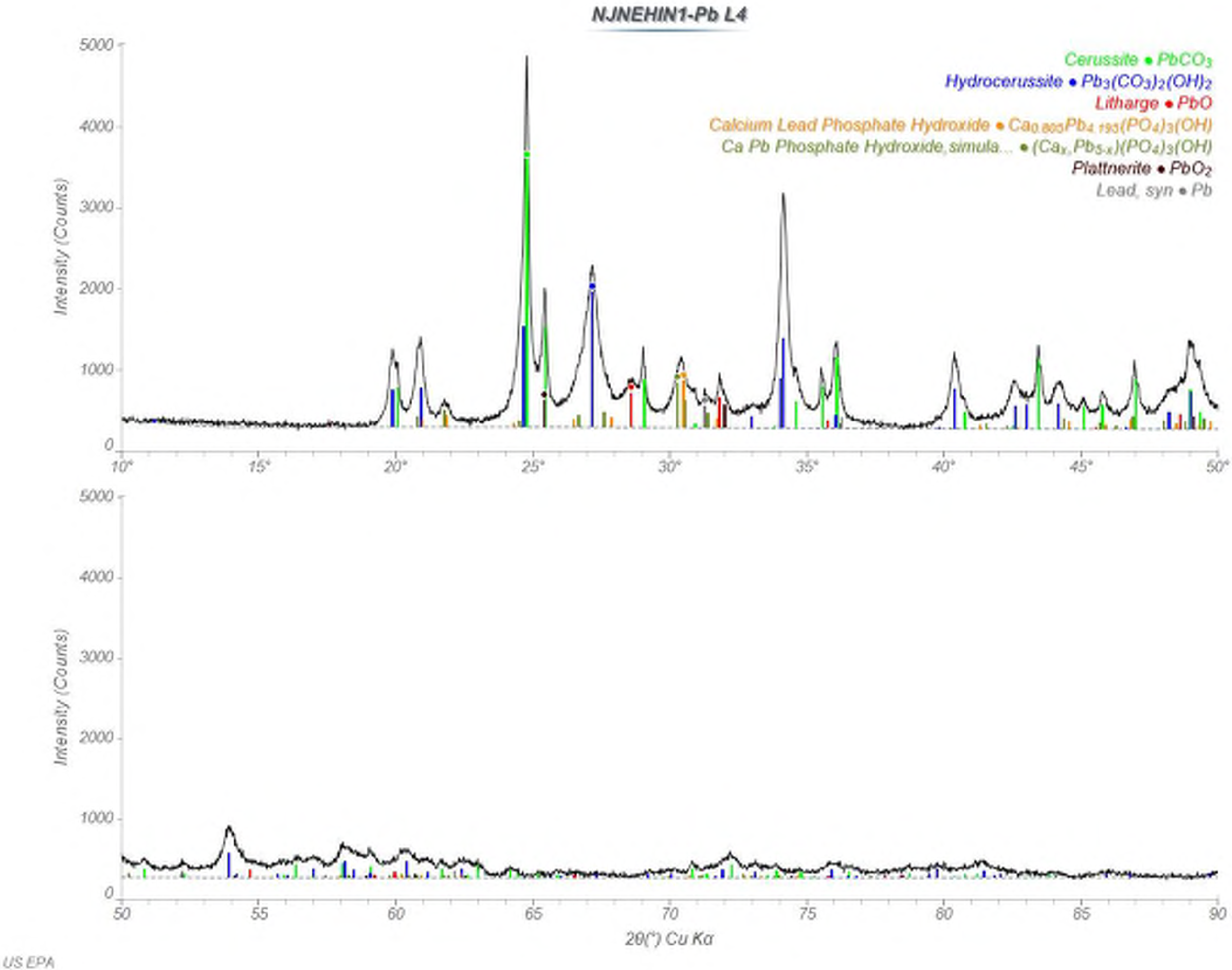
Epoxy
L1
L2
L3
L4
L5
L1
L2
L3
L4
L5
100.00 um
Lead Pipe Wall

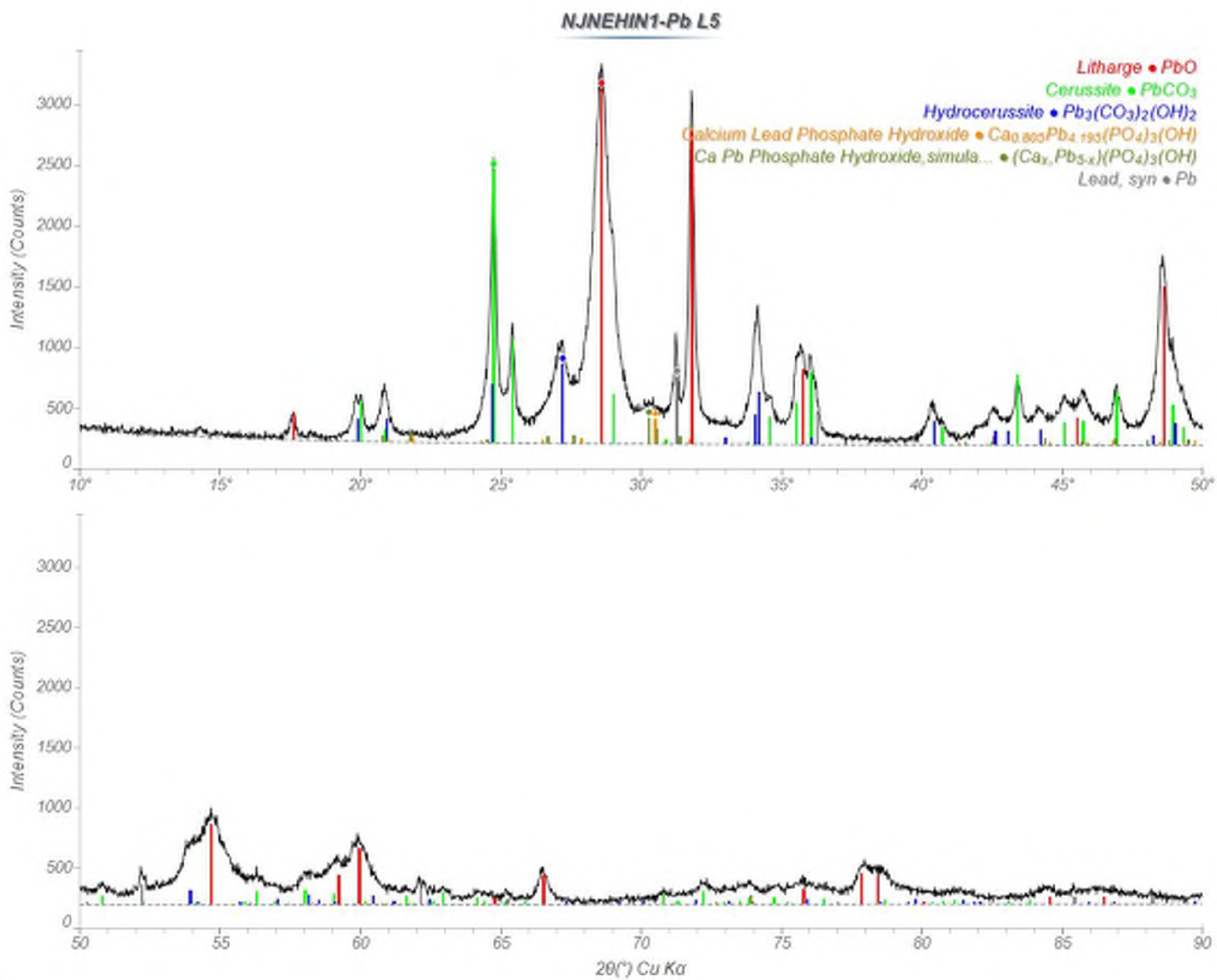

Trench Sediment
Trench Sediment
L1
L2
L3
Trench Sediment


NJNEHIN1-Pb L1
Calcium Lead Phosphate Hydroxide • Ca0.805Pb4.195(PO4)3(OH)
Ca Pb Phosphate Hydroxide, simula... • (Cax,Pb5-x)(PO4)3(OH)
Plattnerite • PbO2
Hydrocerussite • Pb3(CO3)2(OH)2
Quartz • SiO2
Anorthite • CaAl2Si2O8
Intensity (Counts)
0
2000
4000
6000
10°
15°
20°
25°
30°
35°
40°
45°
50°
Intensity (Counts)
0
2000
4000
6000
50
55
60
65
70
75
80
85
90
2θ(°) Cu Kα
US EPA


NJNEHIN1-Pb L2
Calcium Lead Phosphate Hydroxide • Ca0.805Pb4.195(PO4)3(OH)
Ca Pb Phosphate Hydroxide, simula... • (Cax,Pb5-x)(PO4)3(OH)
Plattnerite • PbO2
Cerussite • PbCO3
Hydrocerussite • Pb3(CO3)2(OH)2
Intensity (Counts)
2θ(°) Cu Kα


NJNEHIN1-Pb L3-L4
Calcium Lead Phosphate Hydroxide • Ca0.805Pb4.195(PO4)3(OH)
Ca Pb Phosphate Hydroxide,simula... • (Cax,Pb5-x)(PO4)3(OH)
Plattnerite • PbO2
Cerussite • PbCO3
Hydrocerussite • Pb3(CO3)2(OH)2
Intensity (Counts)
0
1000
2000
3000
10°
15°
20°
25°
30°
35°
40°
45°
50°
Intensity (Counts)
0
1000
2000
3000
50
55
60
65
70
75
80
85
90
2θ(°) Cu Kα
US EPA


NJNEHIN1-Pb L4
Cerussite • $PbCO_3$
Hydrocerussite • $Pb_3(CO_3)_2(OH)_2$
Litharge • PbO
Calcium Lead Phosphate Hydroxide • $Ca_{0.805}Pb_{4.195}(PO_4)_3(OH)$
Ca Pb Phosphate Hydroxide, simula... • $(Ca_x, Pb_{5-x})(PO_4)_3(OH)$
Plattnerite • PbO_2
Lead, syn • Pb
Intensity (Counts)
0
1000
2000
3000
4000
5000
10°
15°
20°
25°
30°
35°
40°
45°
50°
50
55
60
65
70
75
80
85
90
2θ(°) Cu Kα
US EPA

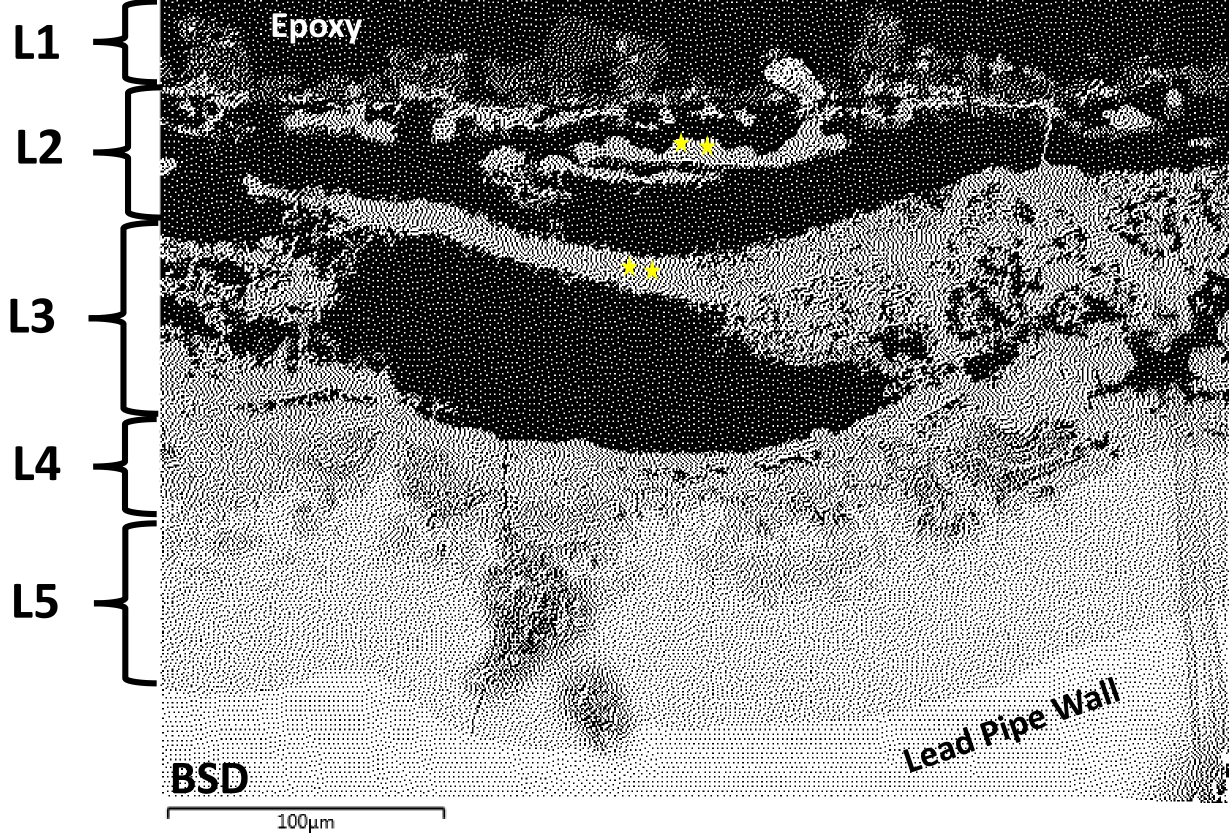

NJNEHIN1-Pb L5
Litharge • PbO
Cerussite • PbCO3
Hydrocerussite • Pb3(CO3)2(OH)2
Calcium Lead Phosphate Hydroxide • Ca0.805Pb4.195(PO4)3(OH)
Ca Pb Phosphate Hydroxide,simula... • (Cax,Pb5-x)(PO4)3(OH)
Lead, syn • Pb
Intensity (Counts)
2θ(°) Cu Kα

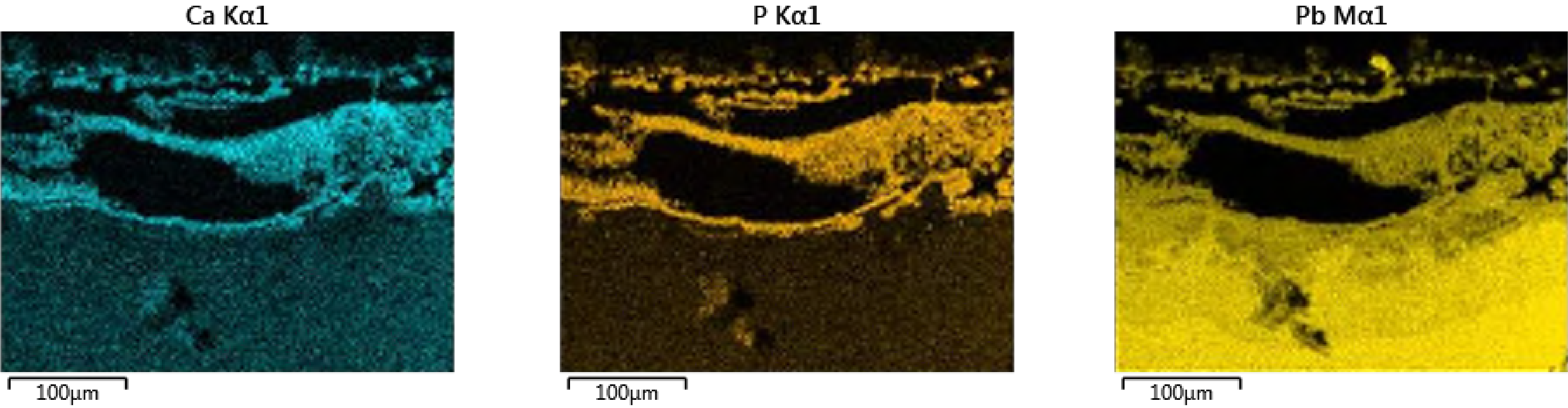
US EPA

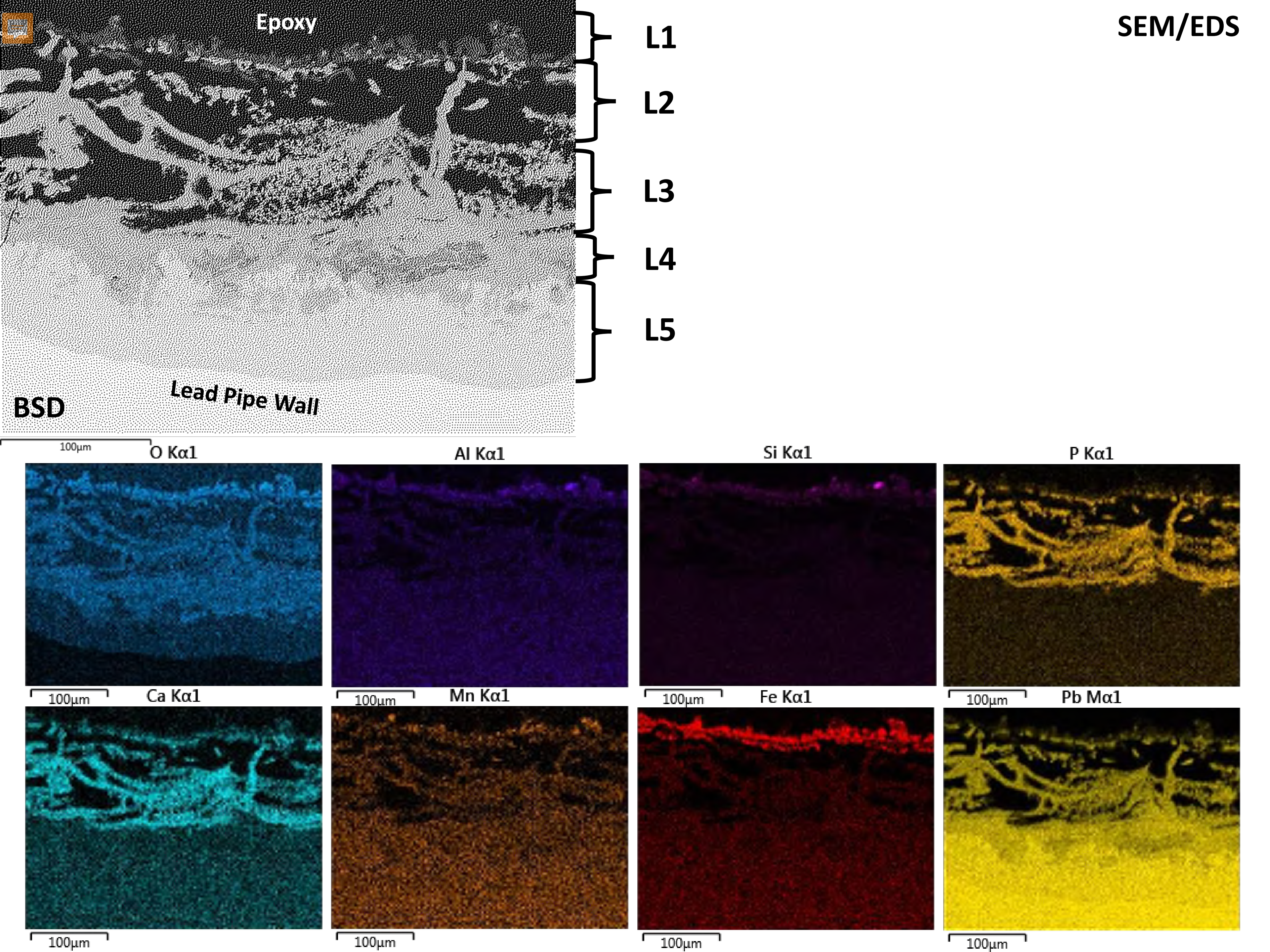
SEM/EDS

EDS Results Normalized to 100%	
Elements	Average (Wt %)
C*	1.3
O	17.6
Al	0.2
P	6.2
Ca	3.5
Fe	0.6
Pb	71.0

*C value was obtained by combustion

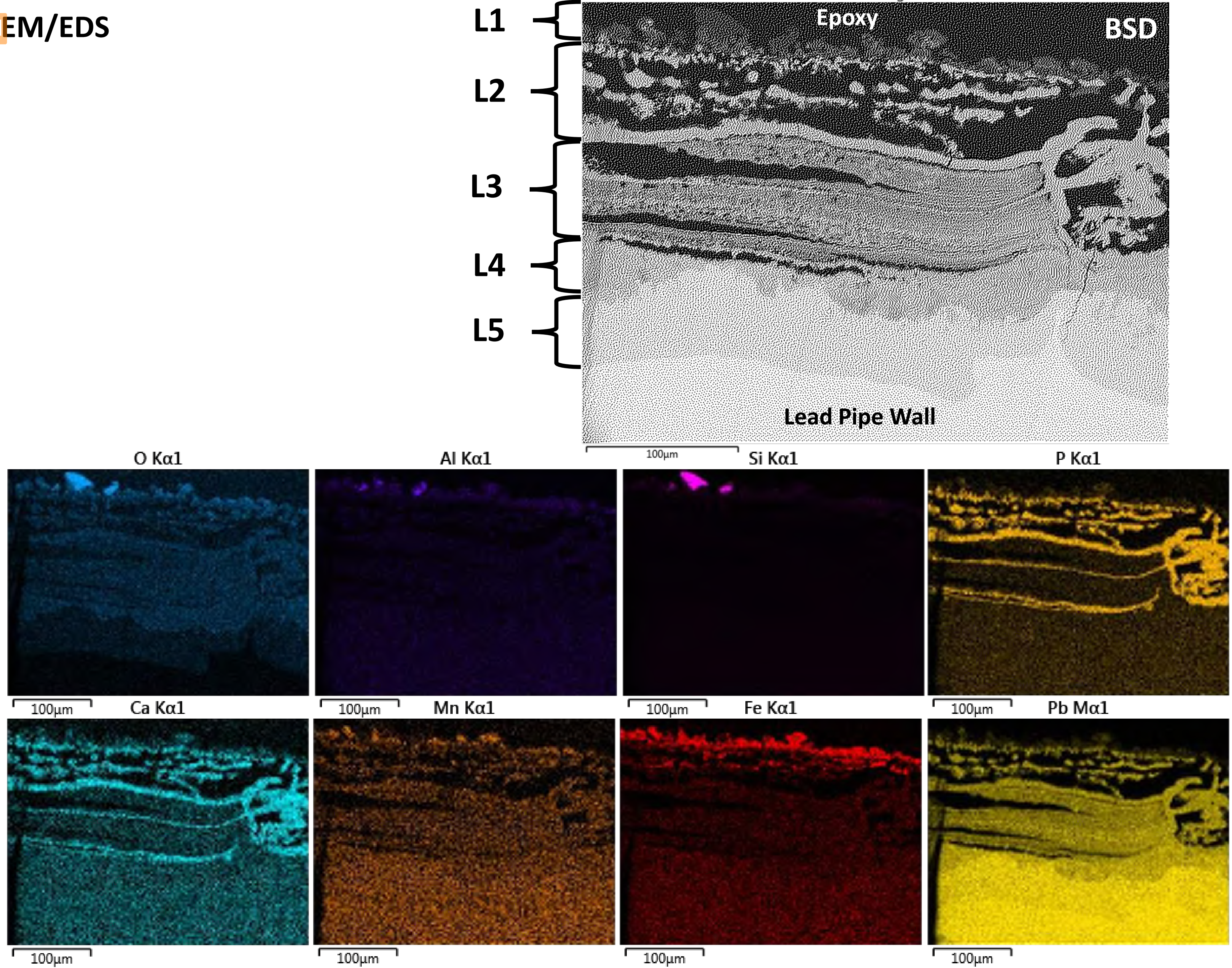




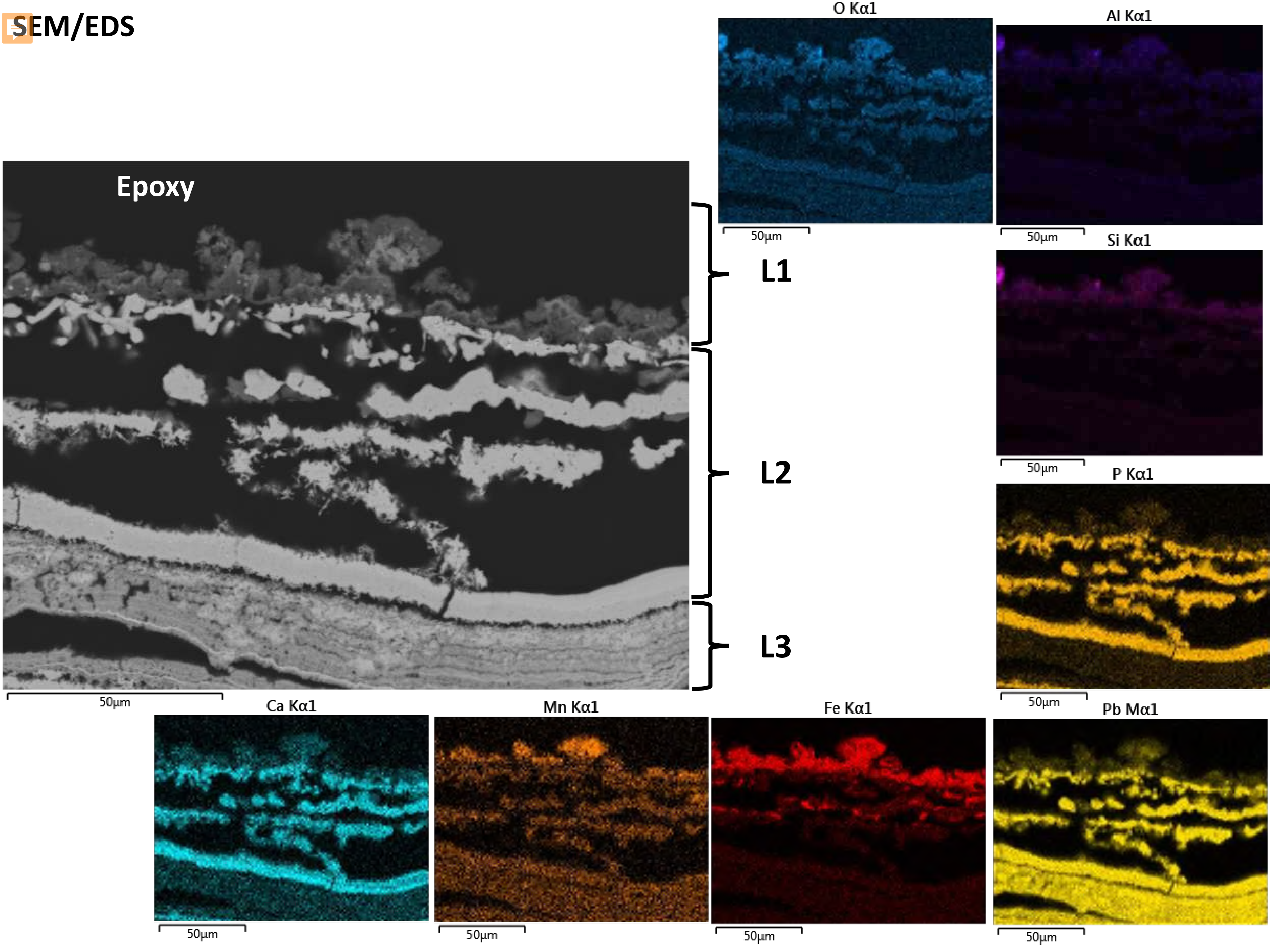


SEM/EDS
Epoxy
L1
L2
L3
L4
L5
BSD
Lead Pipe Wall
100µm
O Kα1
Al Kα1
Si Kα1
P Kα1
Ca Kα1
Mn Kα1
Fe Kα1
Pb Mα1

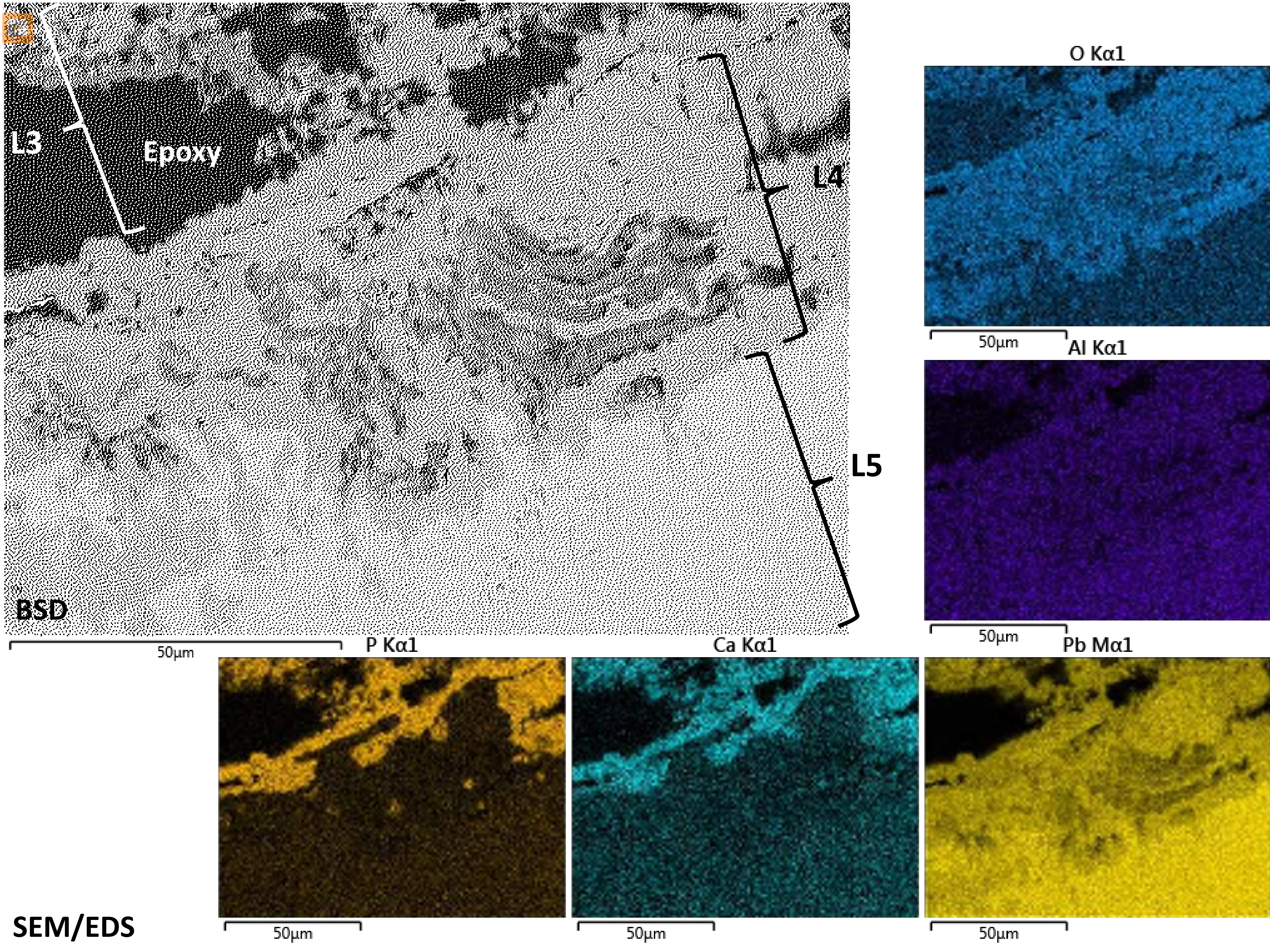
SEM/EDS

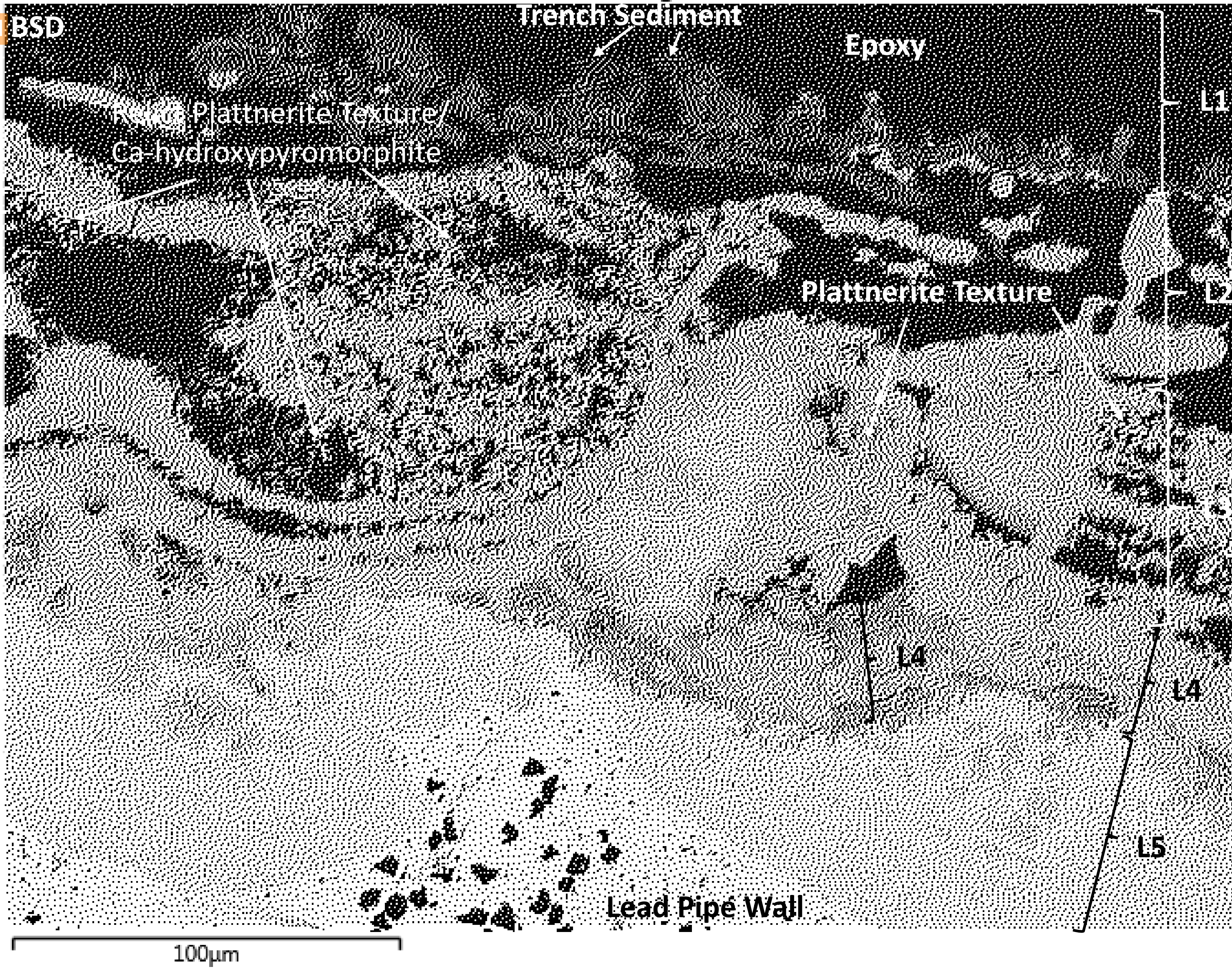

L1
L2
L3
L4
L5
Epoxy
BSD
Lead Pipe Wall
100µm
O Kα1
Al Kα1
Si Kα1
P Kα1
100µm
100µm
100µm
100µm
Ca Kα1
Mn Kα1
Fe Kα1
Pb Mα1
100µm
100µm
100µm
100µm

SEM/EDS



Epoxy
L1
L2
L3
50μm
O Kα1
Al Kα1
Si Kα1
P Kα1
Ca Kα1
Mn Kα1
Fe Kα1
Pb Mα1


L3
Epoxy
L4
L5
BSD
50µm
O Kα1
50µm
Al Kα1
50µm
P Kα1
Ca Kα1
Pb Mα1
SEM/EDS
50µm
50µm
50µm

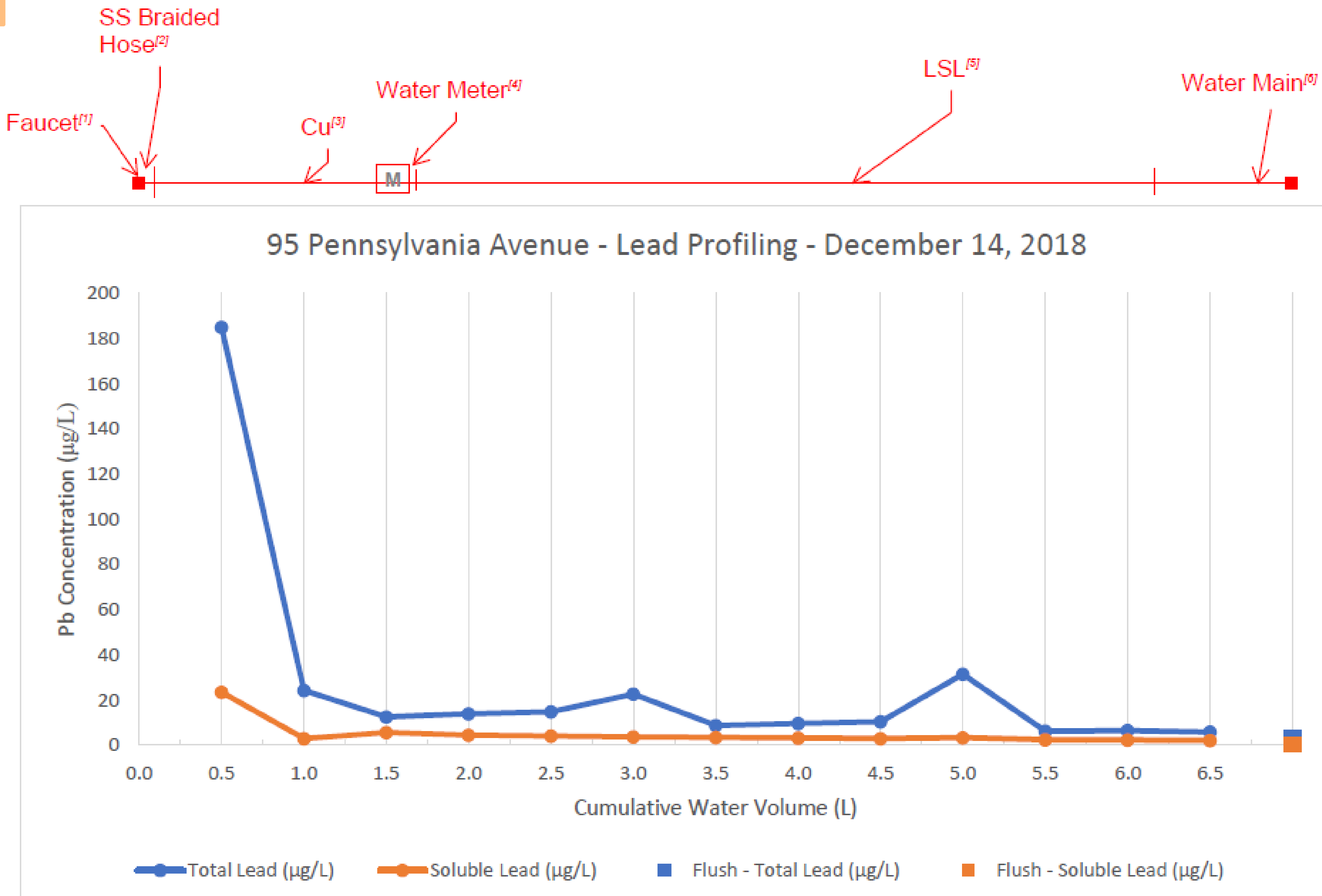


BSD
Trench Sediment
Epoxy
L1
Plattnerite Texture/
Ca-hydroxypyromorphite
Plattnerite Texture
L2
L4
L4
L5
Lead Pipe Wall
100µm

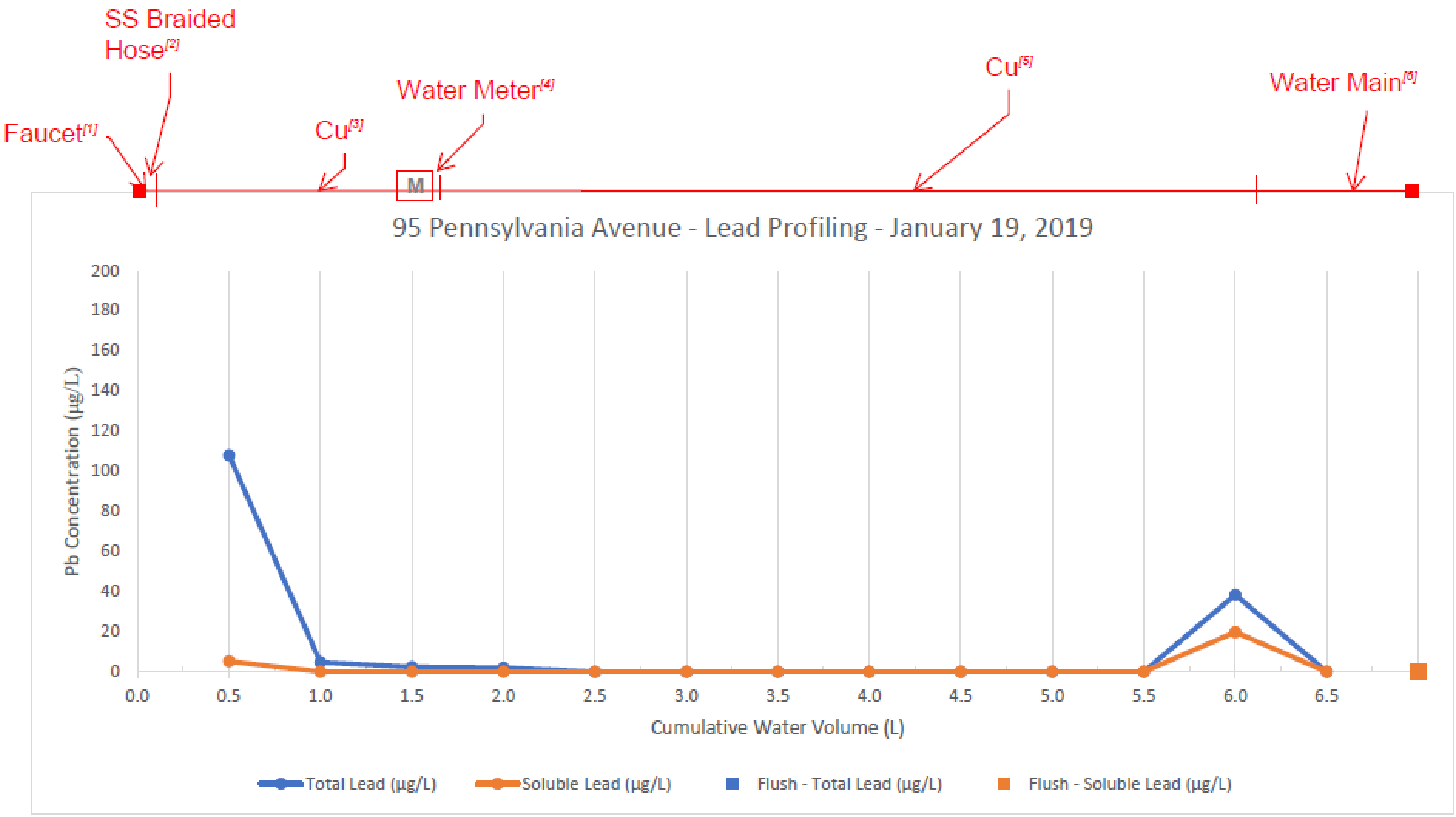
EDS Results, Normalized to 100%
Elemental Concentrations as Average wt%

NJNEHIN1-Pb					
Elements	**L1**	**L2**	**L3/L4**	**L4**	**L5**
***C**	1.01	1.28	1.93	2.98	1.37
O	32.1	22.5	16.4	15.4	12.9
Na	0.4	-	-	-	-
Mg	0.2	-	-	-	-
Al	2.6	0.9	0.2	0.2	0.2
Si	8.8	2.0	-	-	-
P	3.1	4.8	3.2	0.7	0.2
***S**	0.13	0.12	0.15	0.27	0.13
K	0.4	-	-	-	-
Ca	1.5	2.5	1.7	0.4	0.2
Ti	0.2	-	-	-	-
Mn	1.2	0.4	0.1	-	-
Fe	7.5	3.1	0.3	0.1	0.1
Pb	40.8	62.5	75.9	80.1	85.0

*C and S by combustion



Before LSL replacement



After LSL replacement


Newark, NJ
Lead Service Line
Address: 95 Pennsylvania Ave.
Installed: 1887
Removed: December 20, 2018
Tubercles indicated by white arrows

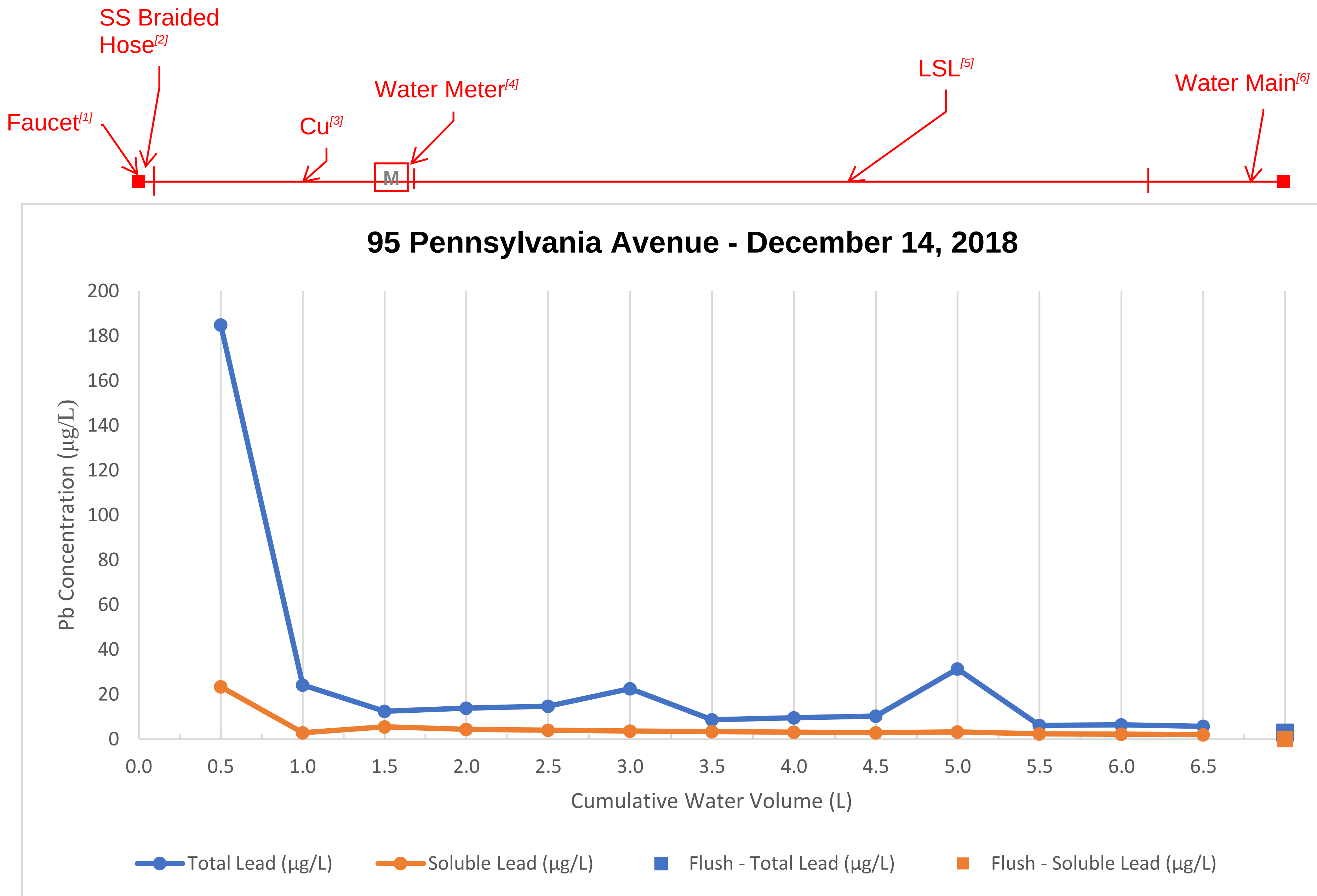

SS Braided Hose[2]
Faucet[1]
Cu[3]
Water Meter[4]
M
LSL[5]
Water Main[6]
95 Pennsylvania Avenue - December 14, 2018
Pb Concentration (µg/L)
200
180
160
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Cumulative Water Volume (L)
Total Lead (µg/L)
Soluble Lead (µg/L)
Flush - Total Lead (µg/L)
Flush - Soluble Lead (µg/L)

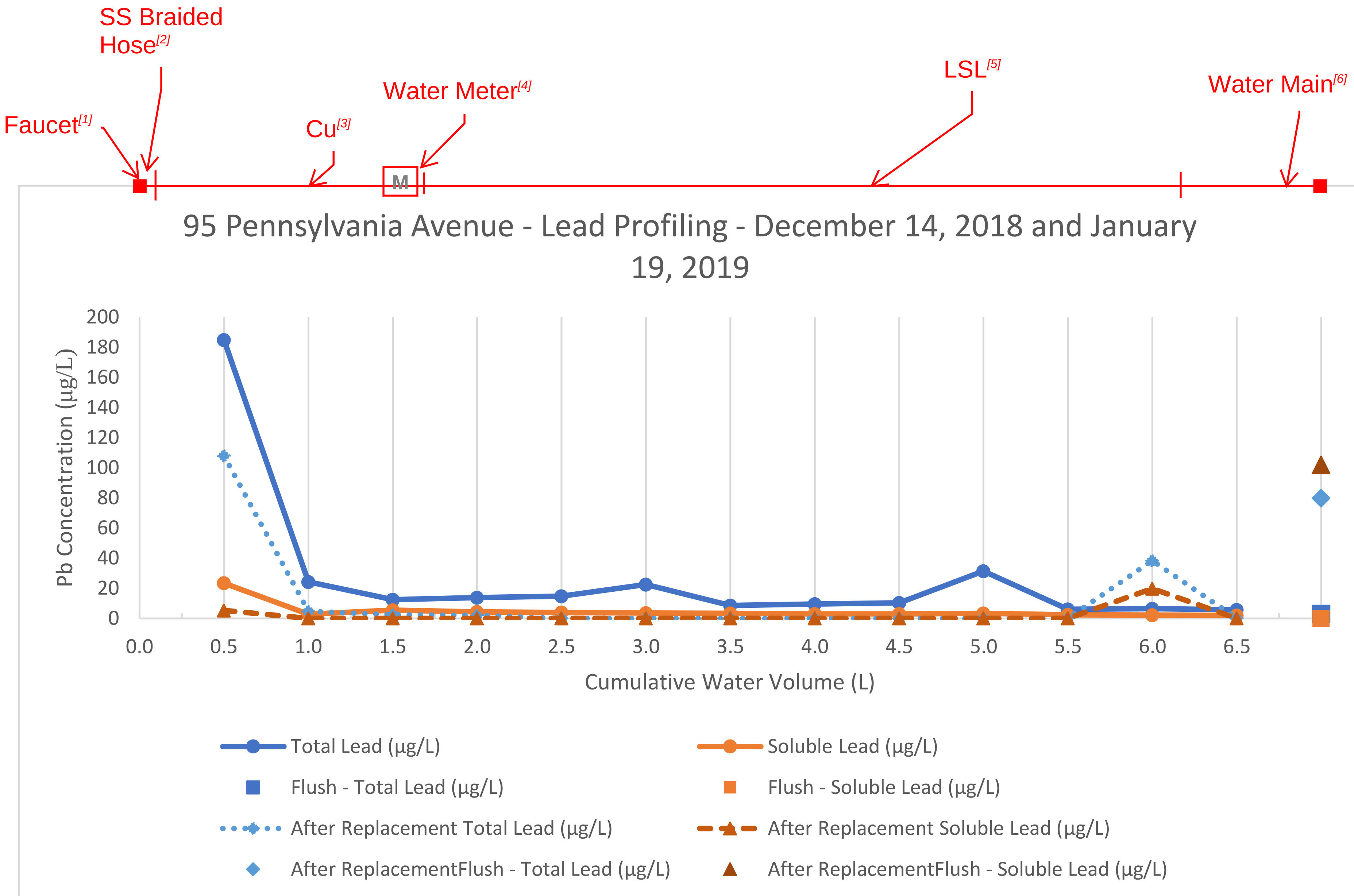
Table 1-1F
City of Newark Sequential Monitoring
Analytical Results
95 Pennsylvania

Site F - 12/14/18

Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters: pH[1]	Temp[1] (degrees C)	Free Cl_2[1] (mg/L)	Total Pb (µg/L)	Dissolved Pb (µg/L)	Total Cu (mg/L)	Alk. (mg/L as $CaCO_3$)	Cond. umhos/cm	Orthophosphate (mg/L as P)	Silica (mg/L as SiO2)	Location/ Description
F1	500	500	After Stagnation	N/A	N/A	N/A	185	23.4	0.0596	33.0	251	0.396		Faucet (28% SS Flex) and Copper Piping with Lead Solder (72%)
F2	500	1000	After Stagnation				24.2	2.86	0.0737			0.48	3.75	Copper Piping with Lead Solder (100%)
F3	500	1500	After Stagnation				12.5	5.52	<.0500			0.497		Copper Piping with Lead Solder (100%)
F4	500	2000	After Stagnation				13.8	4.41	0.0521			0.5		Copper Piping (14%), Lead Piping (86%)
F5	500	2500	After Stagnation				14.7	4	<.05			0.516		Lead Piping (100%)
F6	500	3000	After Stagnation	N/A	N/A	N/A	22.6	3.63	0.0576	31	252	0.503	3.64	Lead Piping (100%)
F7	500	3500	After Stagnation				8.68	3.37	0.0551			0.517		Lead Piping (100%)
F8	500	4000	After Stagnation				9.53	3.07	<.05			0.52		Lead Piping (100%)
F9	500	4500	After Stagnation				10.3	2.94	0.239			0.524		Lead Piping (100%)
F10	500	5000	After Stagnation				31.4	3.31	0.0596			0.524		Lead Piping (100%)
F11	500	5500	After Stagnation				6.14	2.38	<.05			0.555		Lead Piping (100%)
F12	500	6000	After Stagnation				6.43	2.21	<.05			0.545		Lead Piping (100%)
F13	500	6500	After Stagnation				5.74	2.04	<.05			0.543		Lead Piping (27%), Water Main (73%)
F14 FLUSH	500	7000	Flushed after the sequential sampling	N/A	N/A	N/A	2.96	<2.0	<.05	23.0	248	0.546	3.24	Water Main (100%)

NOTES
1. pH, temperature, and free and total chlorine will be field measured.
2. **HOMEOWNER SHOULD FLUSH THE LINE FOR 10 MINUTES BEFORE BEGINNING STAGNATION PERIOD (i.e. night before sampling).**

CDM Smith



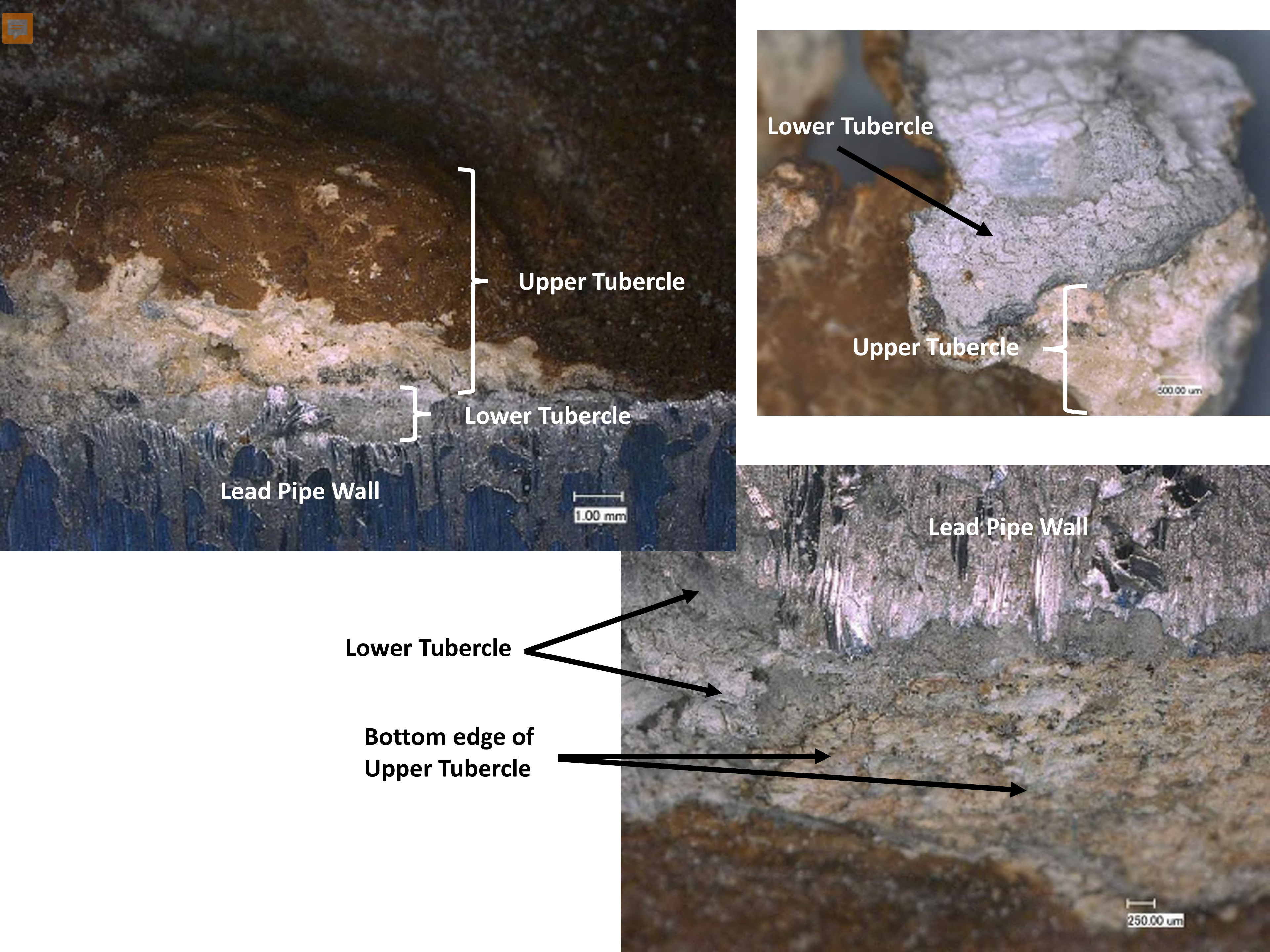
SS Braided Hose[2]
Faucet[1]
Cu[3]
Water Meter[4]
M
LSL[5]
Water Main[6]
95 Pennsylvania Avenue - Lead Profiling - December 14, 2018 and January 19, 2019
Pb Concentration (µg/L)
200
180
160
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
Cumulative Water Volume (L)
Total Lead (µg/L)
Soluble Lead (µg/L)
Flush - Total Lead (µg/L)
Flush - Soluble Lead (µg/L)
After Replacement Total Lead (µg/L)
After Replacement Soluble Lead (µg/L)
After ReplacementFlush - Total Lead (µg/L)
After ReplacementFlush - Soluble Lead (µg/L)

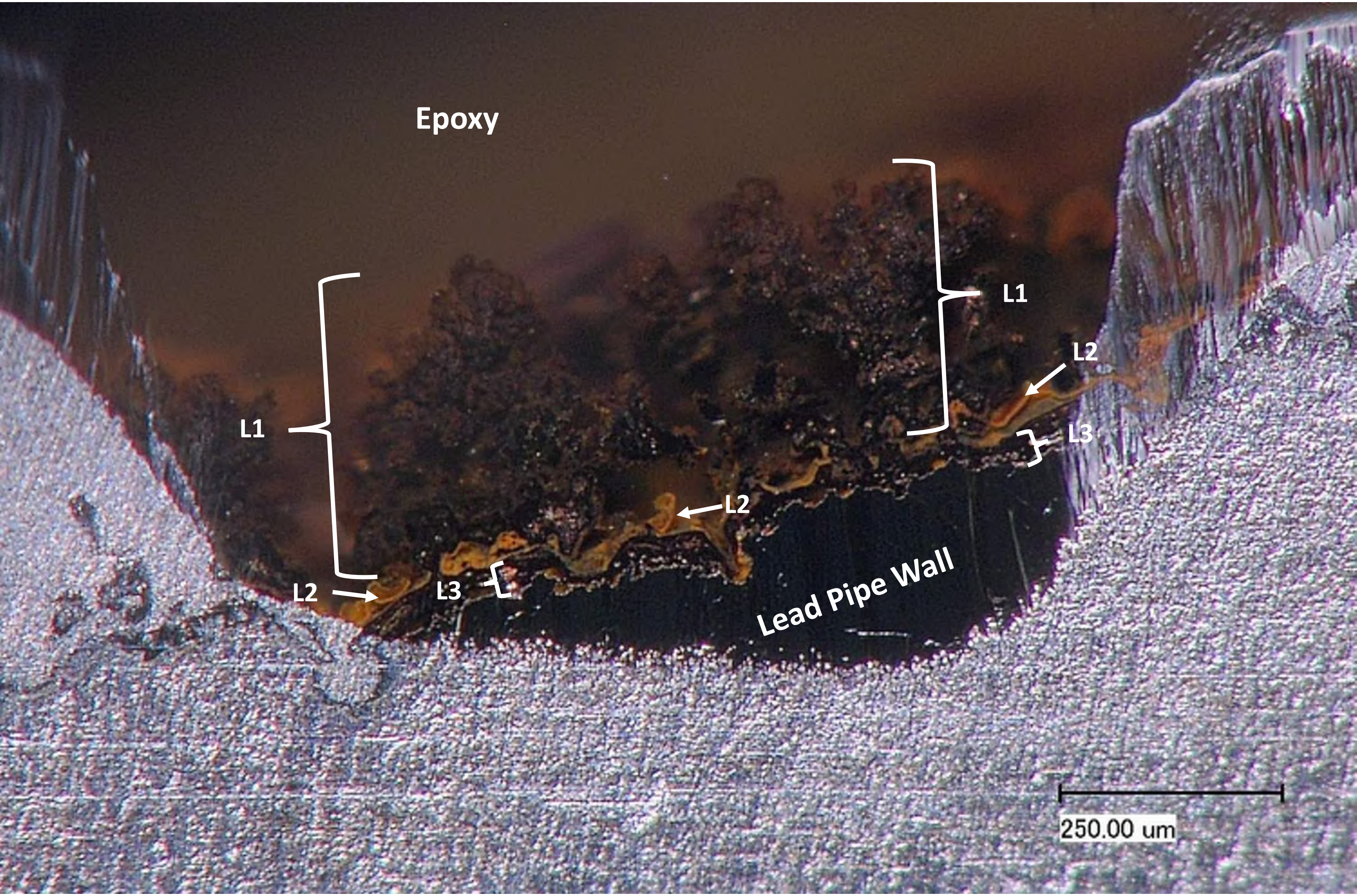
Table 1-1L
City of Newark Sequential Monitoring
Analytical Results
95 Pennsylvania
After Lead Service Line Replacement

Site L -1/19/19

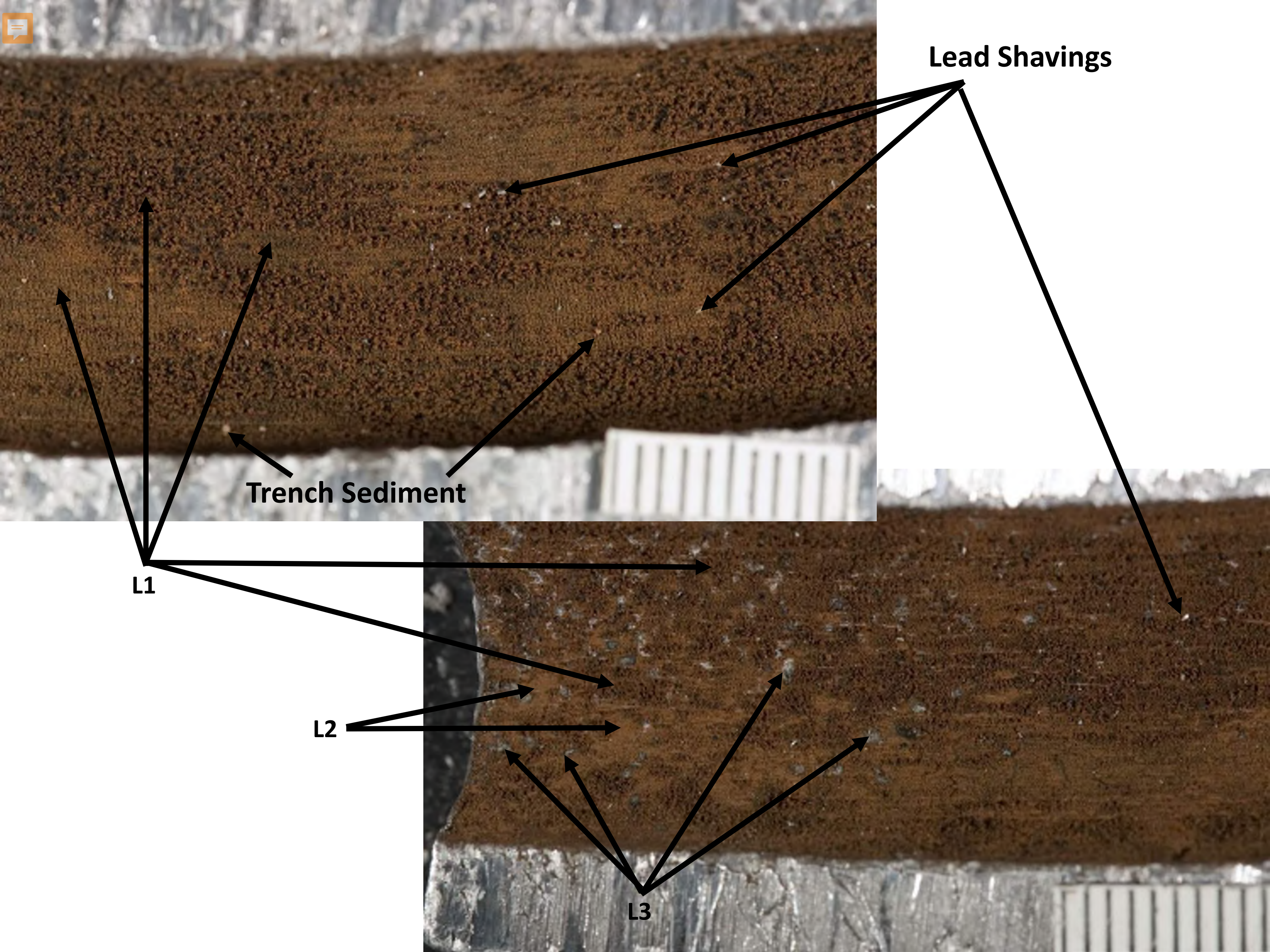
Sample	Volume (mL)	Cumulative Volume (mL)	Collection	Water Quality Parameters										Location/ Description
				pH[1]	Temp[1]	Free Cl_2[1]	Total Pb	Dissolved Pb	Total Cu	Alk.	Cond.	Orthophosphate	Silica	
					(degrees C)	(mg/L)	(µg/L)	(µg/L)	(mg/L)	(mg/L as $CaCO_3$)	umhos/cm	(mg/L as P)	(mg/L as SiO2)	
L1	500	500	After Stagnation	6.97	15.0	0.04	108.00	5.24	<.05	34.0	215			Faucet (28% SS Flex) and Copper Piping with Lead Solder (72%)
L2	500	1000	After Stagnation				4.75	<2	0.072			0.739		Copper Piping with Lead Solder (100%)
L3	500	1500	After Stagnation				2.40	<2	0.118					Copper Piping with Lead Solder (100%)
L4	500	2000	After Stagnation				2.06	<2	0.147					Copper Piping (14%), Lead Piping (86%)
L5	500	2500	After Stagnation				<2	<2	0.153					Lead Piping (100%)
L6	500	3000	After Stagnation	6.99	12.8	0.06	<2	<2	0.170	31	244			Lead Piping (100%)
L7	500	3500	After Stagnation				<2	<2	0.206			0.686		Lead Piping (100%)
L8	500	4000	After Stagnation				<2	<2	0.194					Lead Piping (100%)
L9	500	4500	After Stagnation				<2	<2	0.198					Lead Piping (100%)
L10	500	5000	After Stagnation				<2	<2	0.162					Lead Piping (100%)
L11	500	5500	After Stagnation				<2	<2	0.151					Lead Piping (100%)
L12	500	6000	After Stagnation				38.30	19.8	0.350					Lead Piping (100%)
L13	500	6500	After Stagnation				<2	<2	0.151					Lead Piping (27%), Water Main (73%)
L14 FLUSH	500	7000	Flushed after the sequential sampling	7.07	8.1	0.56	<2	<2	0.014	25.0	243	1.54		Water Main (100%)

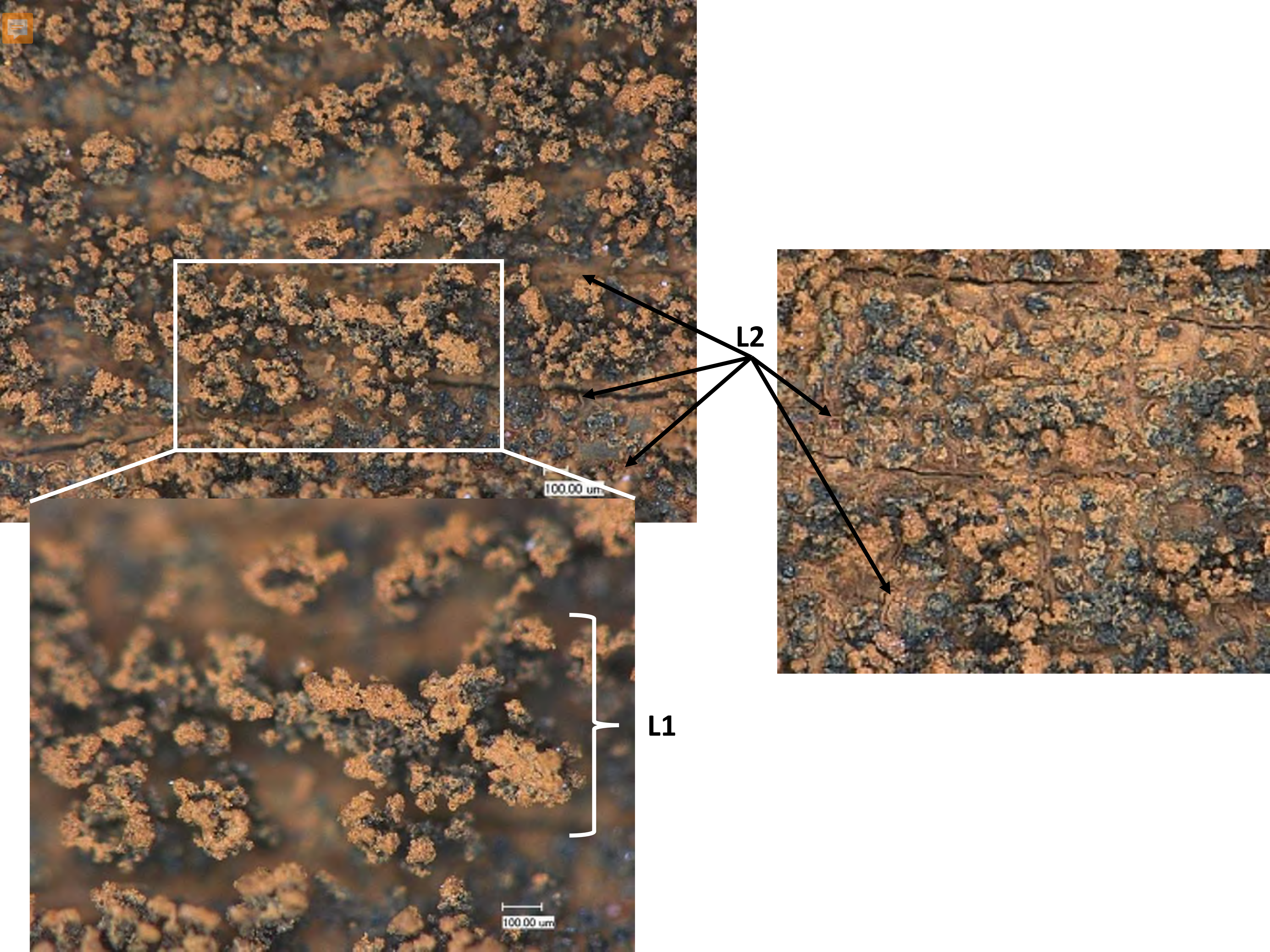
NOTES
1. pH, temperature, and free and total chlorine will be field measured.
2. **HOMEOWNER SHOULD FLUSH THE LINE FOR 10 MINUTES BEFORE BEGINNING STAGNATION PERIOD (i.e. night before sampling).**


Upper Tubercle
Lower Tubercle
Lead Pipe Wall
1.00 mm
Lower Tubercle
Upper Tubercle
500.00 um
Lead Pipe Wall
Lower Tubercle
Bottom edge of
Upper Tubercle
250.00 um

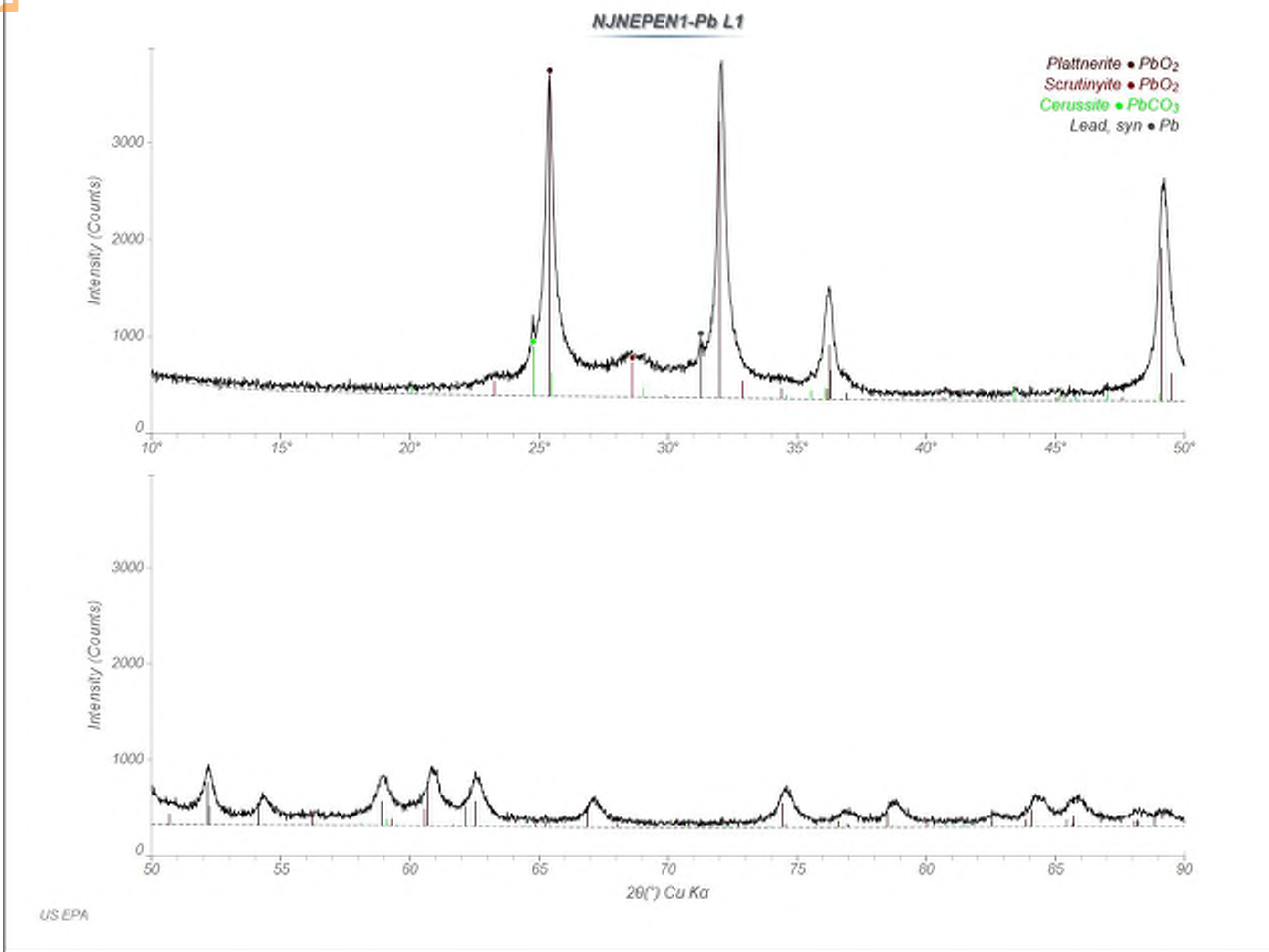


Epoxy
L1
L1
L2
L2
L2
L3
L3
Lead Pipe Wall
250.00 um

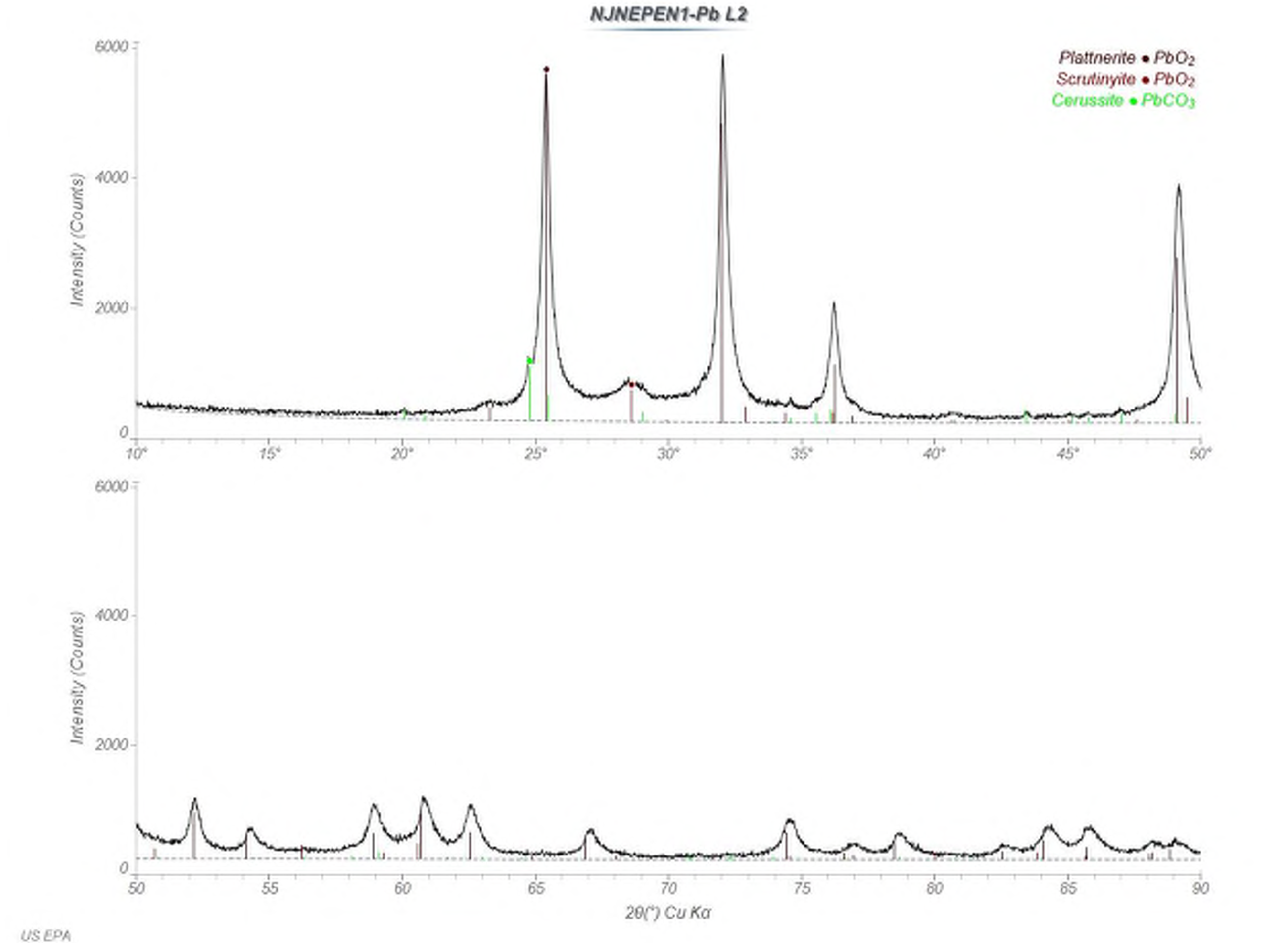

Lead Shavings
Trench Sediment
L1
L2
L3



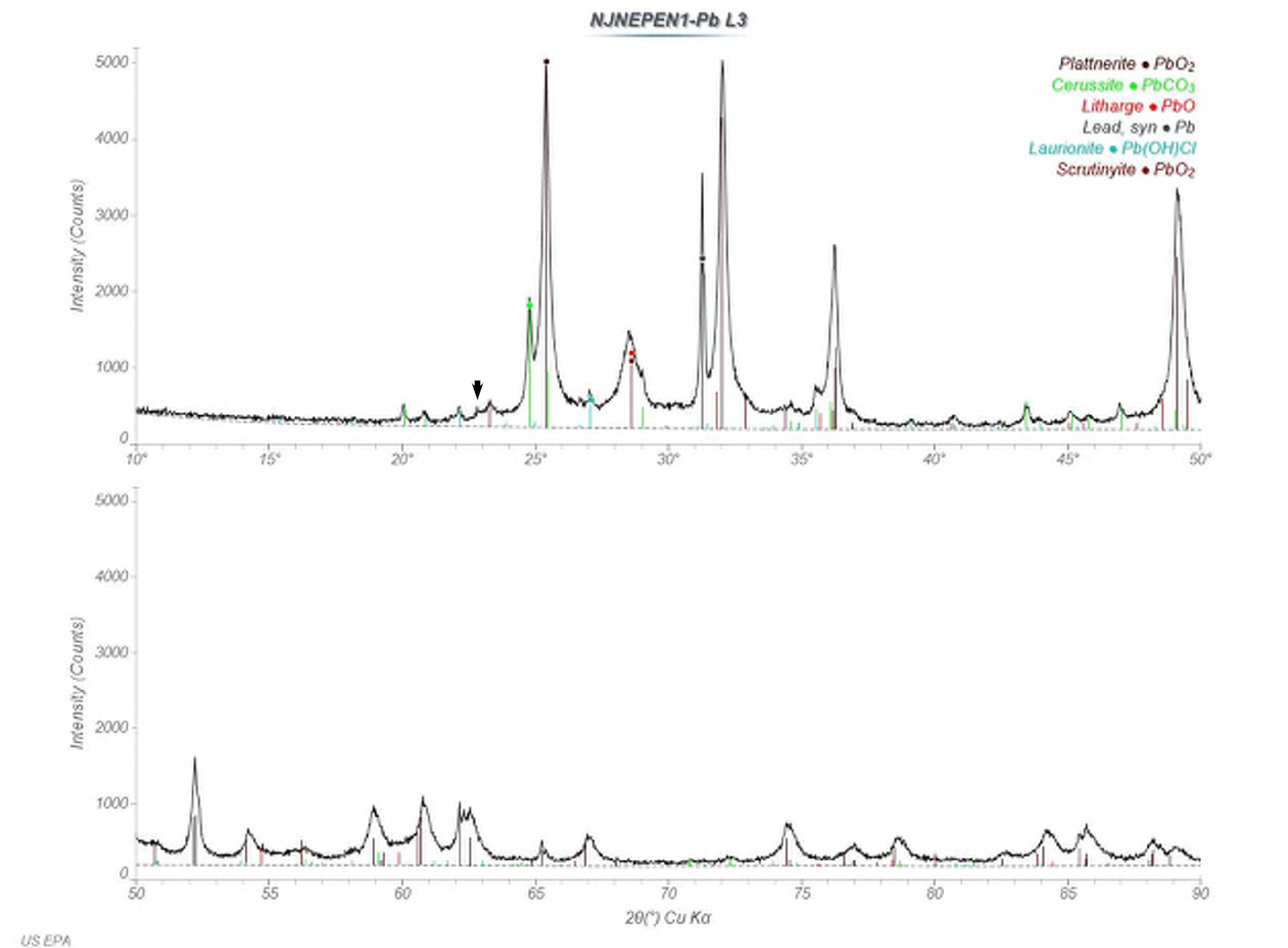
L2
L1
100.00 um
100.00 um

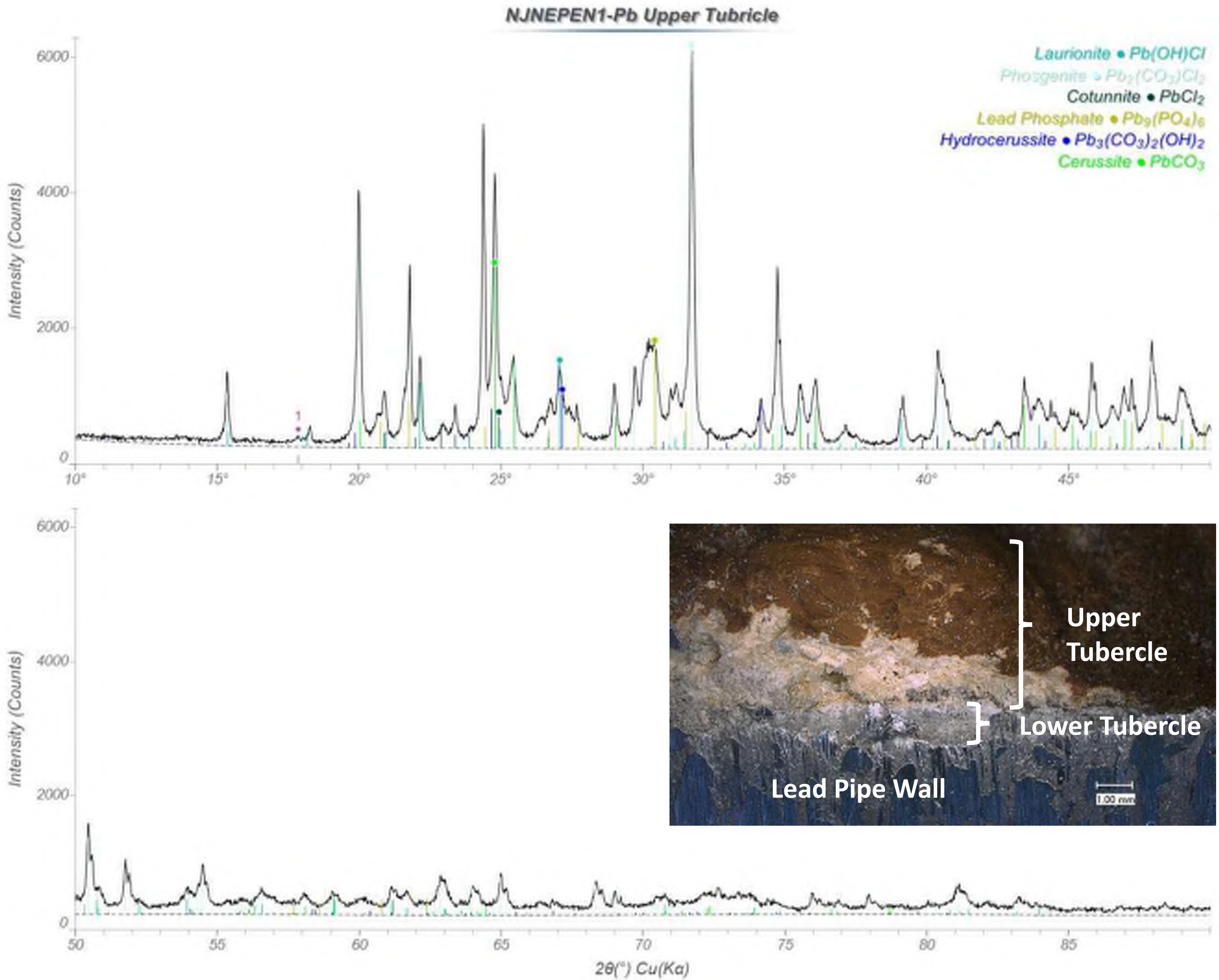


NJNEPEN1-Pb L1
Plattnerite • PbO2
Scrutinyite • PbO2
Cerussite • PbCO3
Lead, syn • Pb
Intensity (Counts)
0
1000
2000
3000
10°
15°
20°
25°
30°
35°
40°
45°
50°
Intensity (Counts)
0
1000
2000
3000
50
55
60
65
70
75
80
85
90
2θ(°) Cu Kα
US EPA

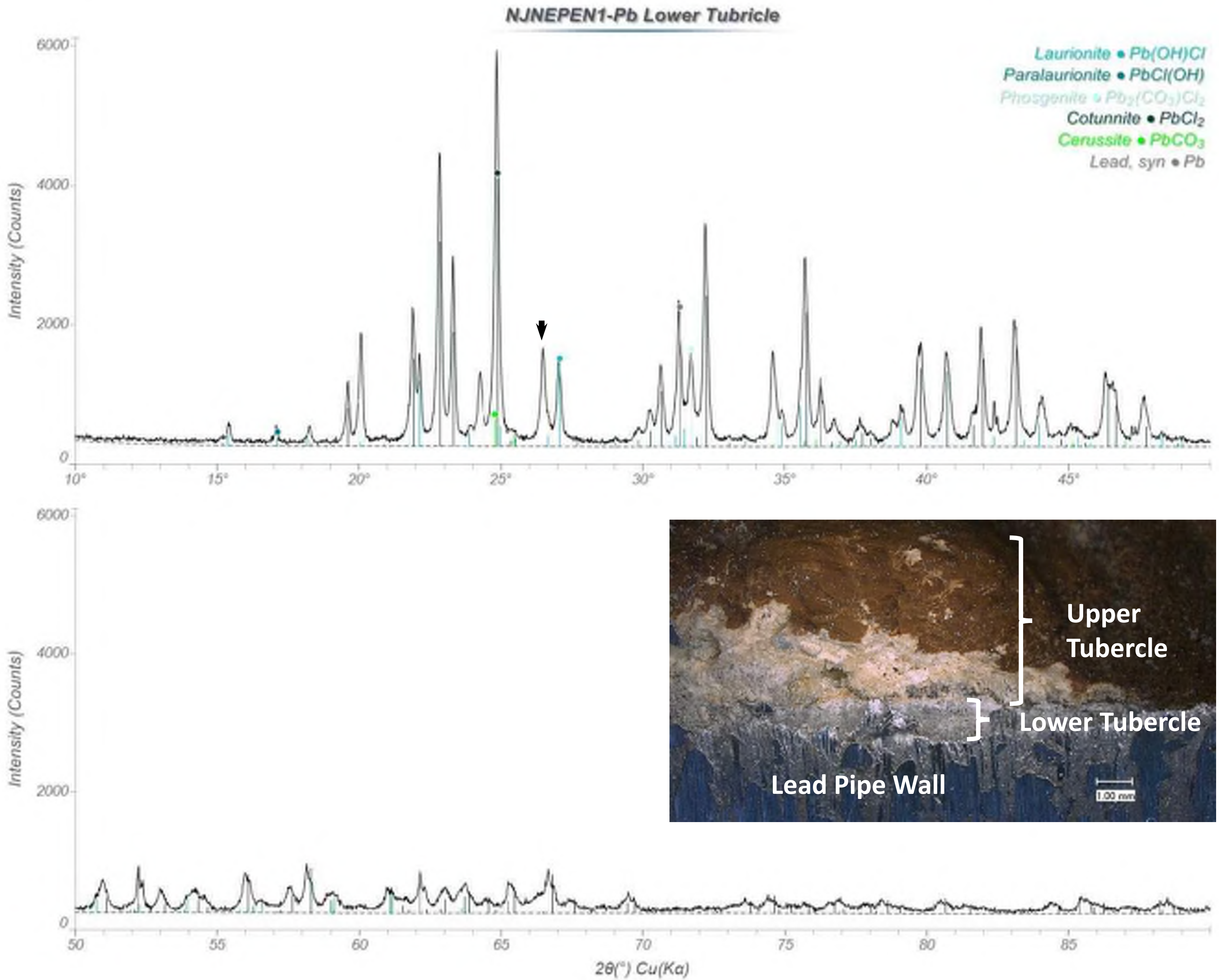


NJNEPEN1-Pb L2
Plattnerite • PbO2
Scrutinyite • PbO2
Cerussite • PbCO3
Intensity (Counts)
6000
4000
2000
0
10°
15°
20°
25°
30°
35°
40°
45°
50°
Intensity (Counts)
6000
4000
2000
0
50
55
60
65
70
75
80
85
90
2θ(°) Cu Kα
US EPA

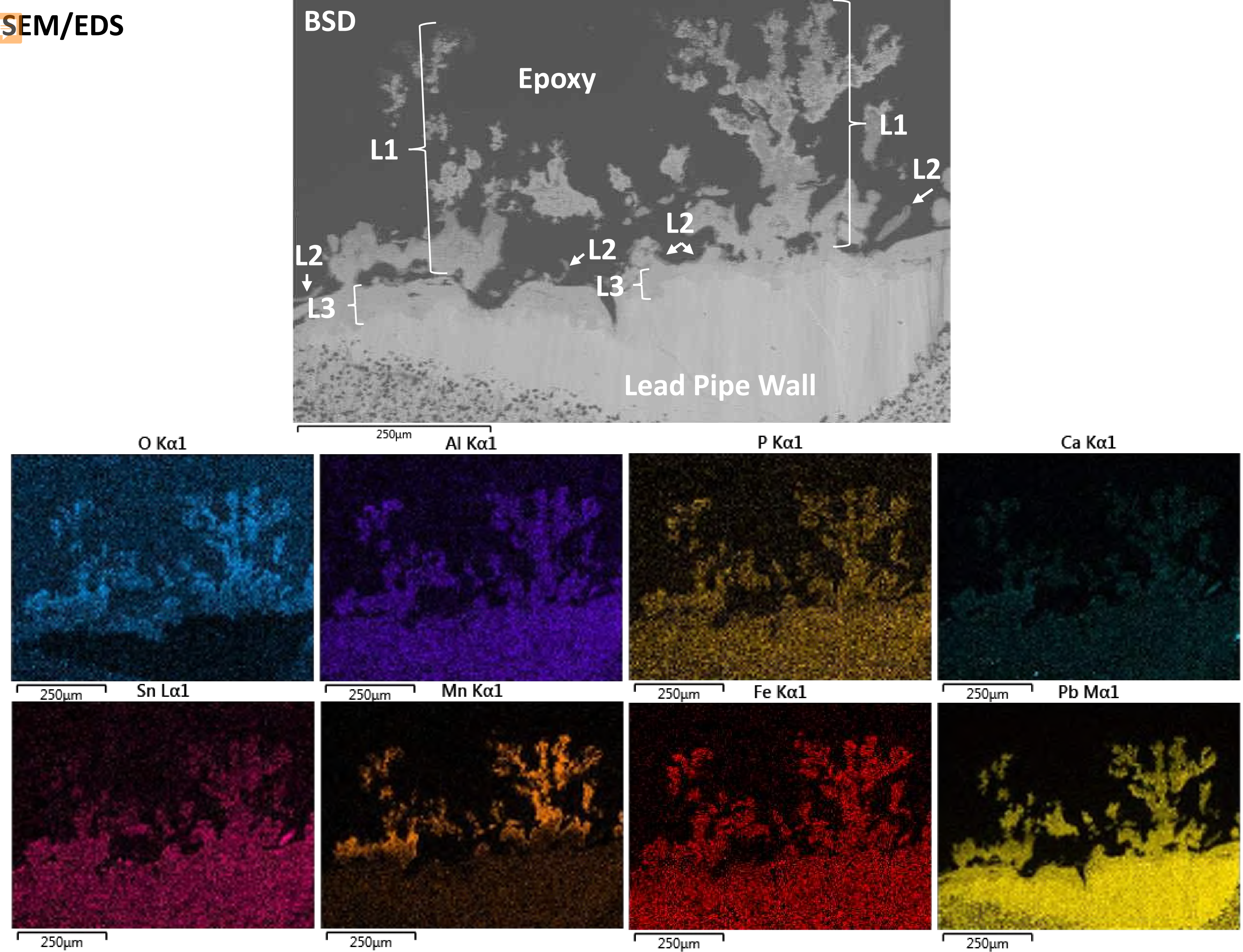

NJNEPEN1-Pb L3
Plattnerite • PbO2
Cerussite • PbCO3
Litharge • PbO
Lead, syn • Pb
Laurionite • Pb(OH)Cl
Scrutinyite • PbO2
Intensity (Counts)
2θ(°) Cu Kα
US EPA

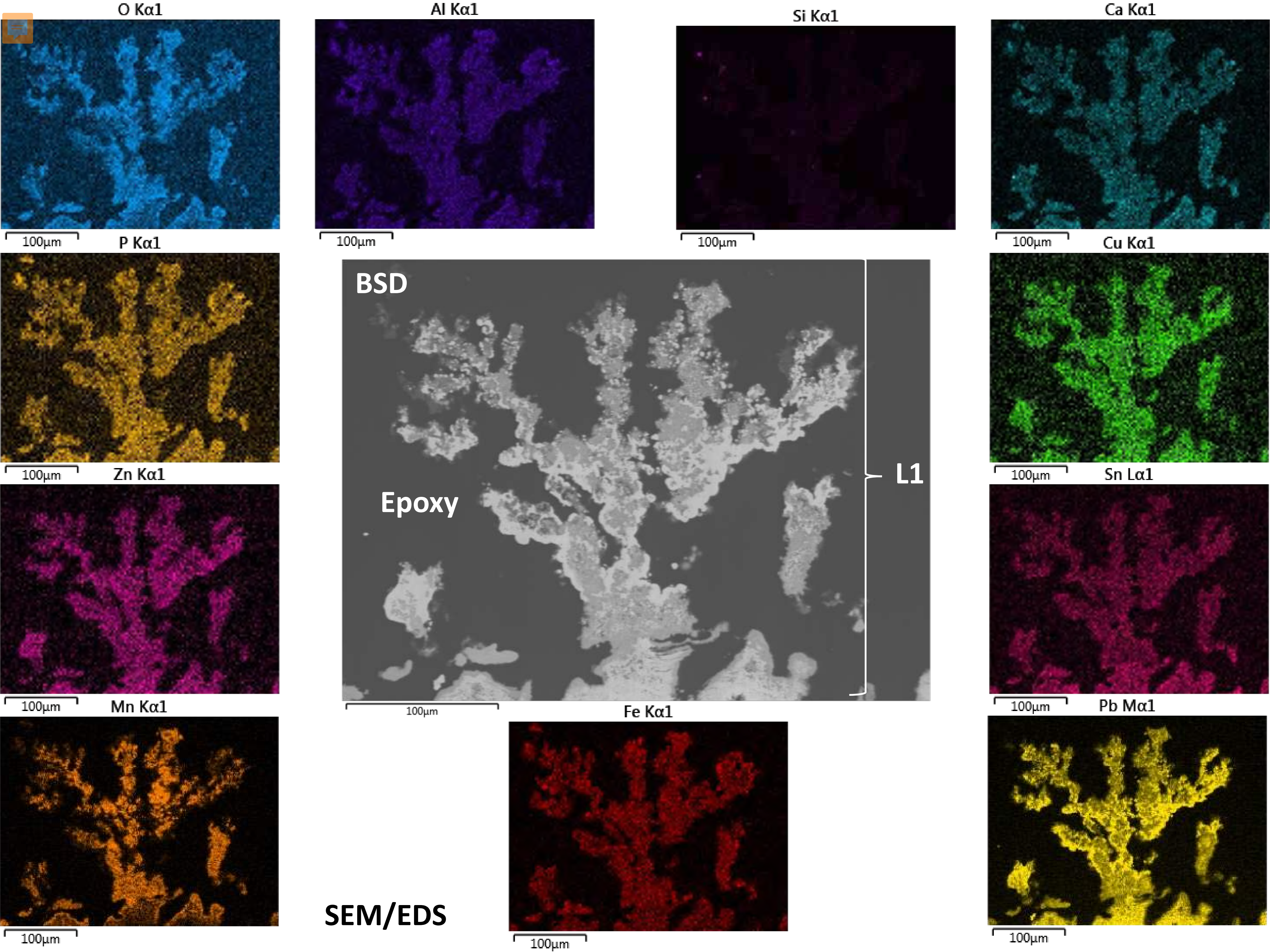


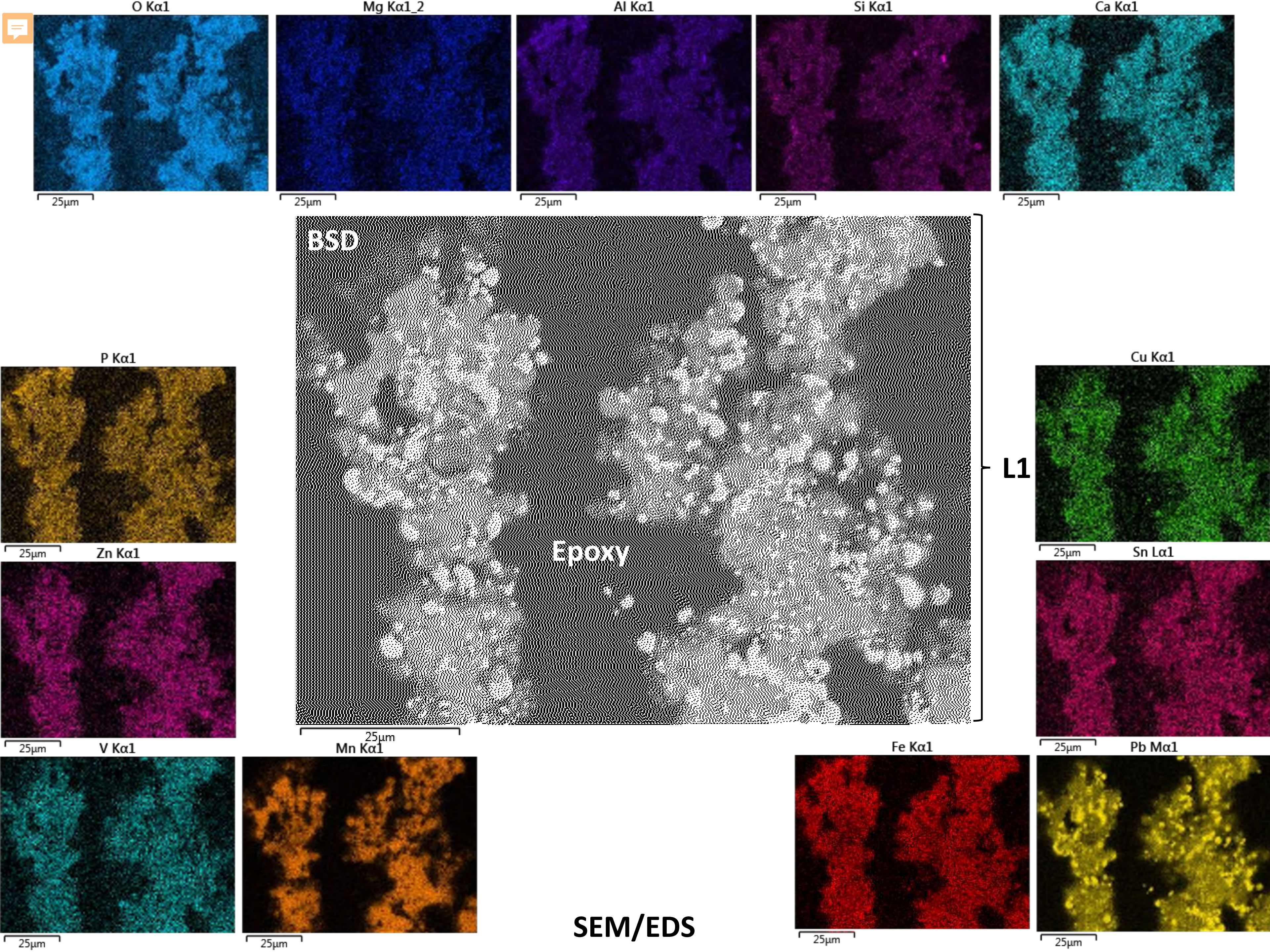
NJNEPEN1-Pb Upper Tubricle
Laurionite • $Pb(OH)Cl$
Phosgenite • $Pb_2(CO_3)Cl_2$
Cotunnite • $PbCl_2$
Lead Phosphate • $Pb_3(PO_4)_6$
Hydrocerussite • $Pb_3(CO_3)_2(OH)_2$
Cerussite • $PbCO_3$
Intensity (Counts)
6000
4000
2000
0
10°
15°
20°
25°
30°
35°
40°
45°
50
55
60
65
70
75
80
85
2θ(°) Cu(Kα)
Upper Tubercle
Lower Tubercle
Lead Pipe Wall
1.00 mm

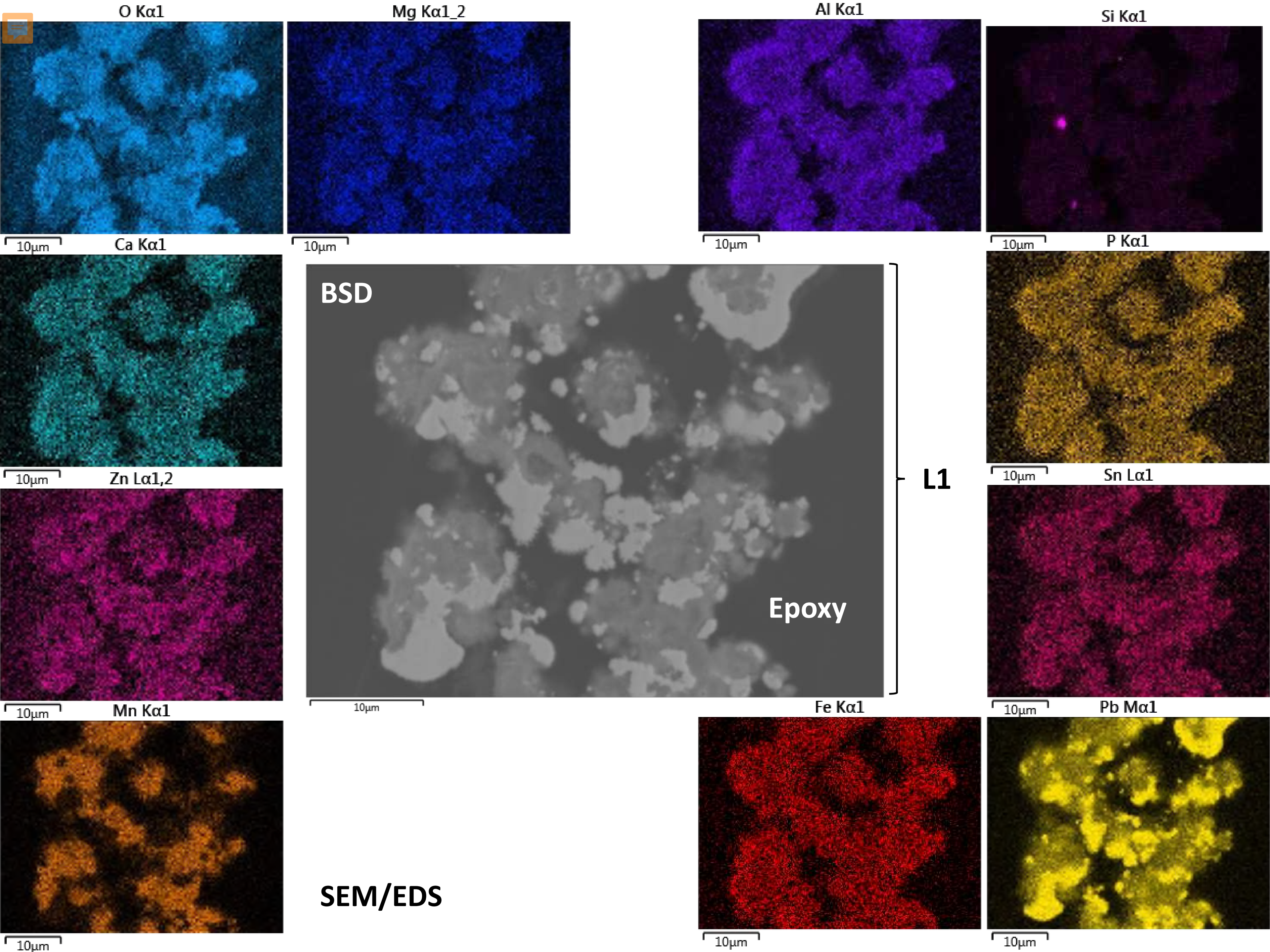

NJNEPEN1-Pb Lower Tubricle
Laurionite • Pb(OH)Cl
Paralaurionite • PbCl(OH)
Phosgenite • Pb2(CO3)Cl2
Cotunnite • PbCl2
Cerussite • PbCO3
Lead, syn • Pb
Intensity (Counts)
2θ(°) Cu(Kα)
Upper Tubercle
Lower Tubercle
Lead Pipe Wall
1.00 mm

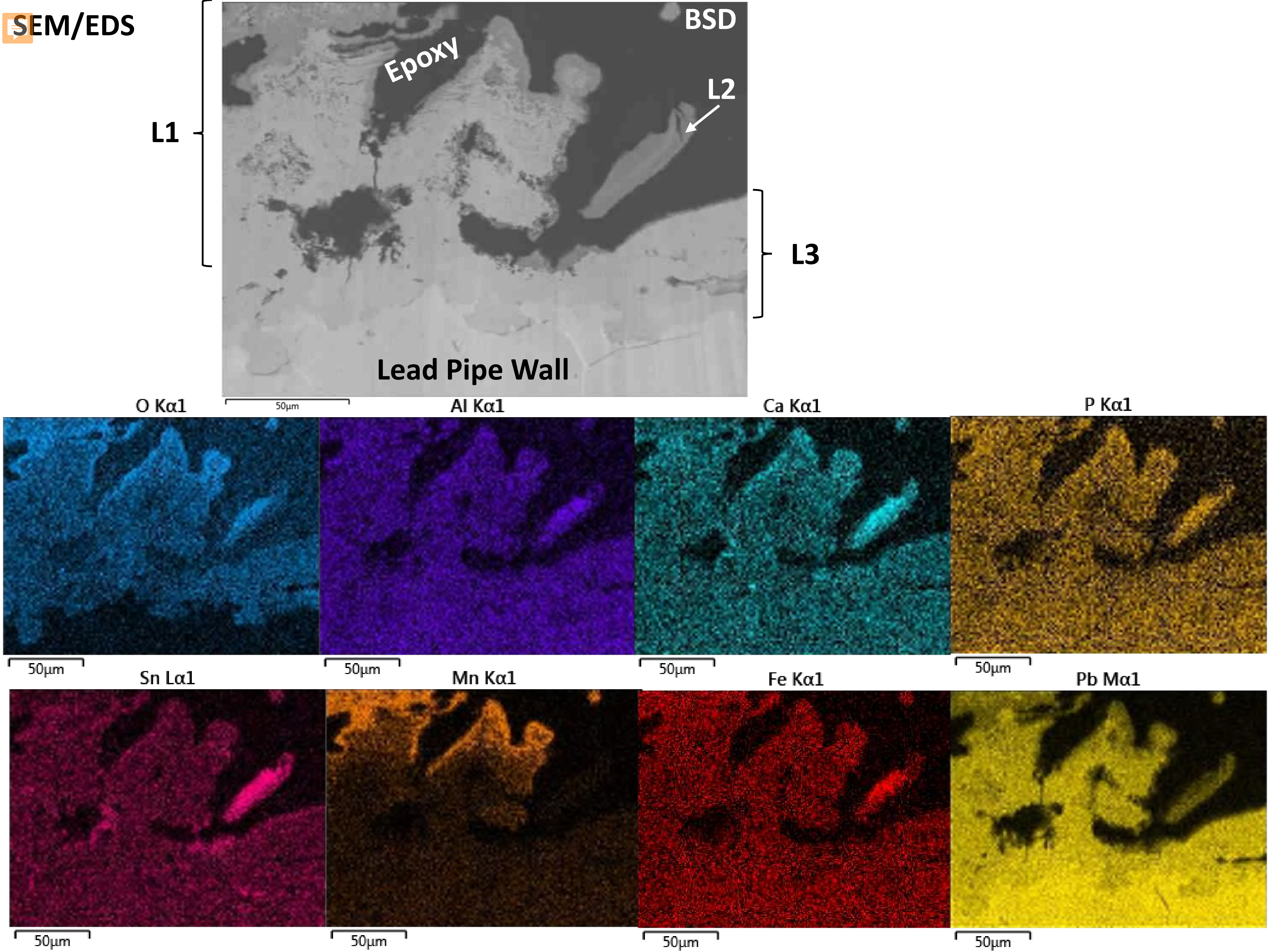
SEM/EDS

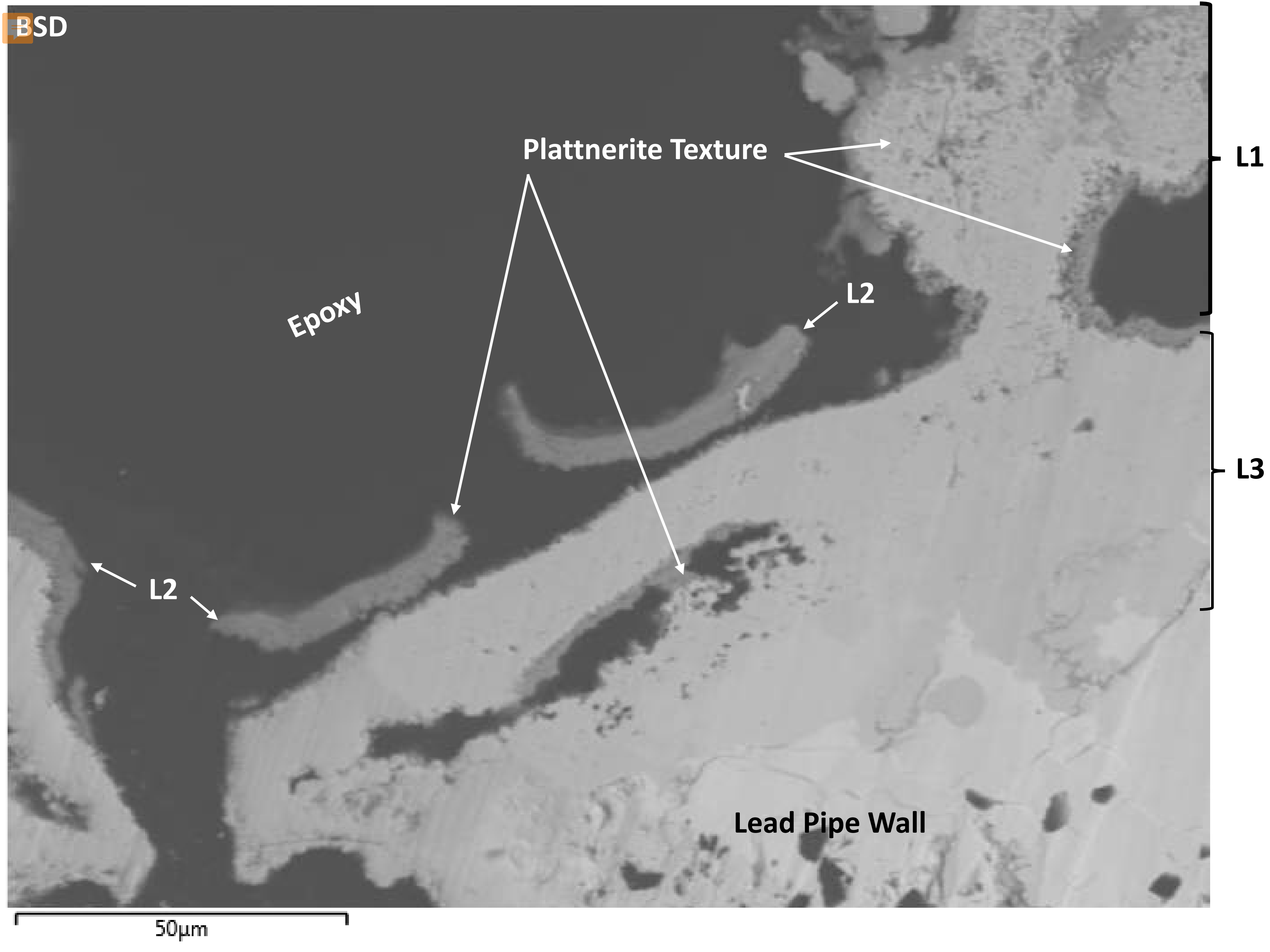

BSD
Epoxy
L1
L1
L2
L2
L2
L2
L3
L3
Lead Pipe Wall
250µm
O Kα1
Al Kα1
P Kα1
Ca Kα1
Sn Lα1
Mn Kα1
Fe Kα1
Pb Mα1
250µm


O Kα1
Al Kα1
Si Kα1
Ca Kα1
P Kα1
Cu Kα1
BSD
Epoxy
L1
Zn Kα1
Sn Lα1
Mn Kα1
Fe Kα1
Pb Mα1
100µm
SEM/EDS


O Kα1
Mg Kα1_2
Al Kα1
Si Kα1
Ca Kα1
25μm
BSD
Epoxy
L1
P Kα1
Cu Kα1
Zn Kα1
Sn Lα1
V Kα1
Mn Kα1
Fe Kα1
Pb Mα1
SEM/EDS


O Kα1
Mg Kα1_2
Al Kα1
Si Kα1
Ca Kα1
P Kα1
BSD
Epoxy
L1
Zn Lα1,2
Sn Lα1
Mn Kα1
Fe Kα1
Pb Mα1
10μm
SEM/EDS


SEM/EDS
BSD
Epoxy
L1
L2
L3
Lead Pipe Wall
50µm
O Kα1
Al Kα1
Ca Kα1
P Kα1
Sn Lα1
Mn Kα1
Fe Kα1
Pb Mα1
50µm


BSD
Plattnerite Texture
Epoxy
L2
L2
L1
L3
Lead Pipe Wall
50µm

EDS Results, Normalized to 100%
Elemental Concentrations as Average wt%

NJNEPEN1-Pb					
Elements	L1	L2	L3	Upper Tubercle	Lower Tubercle
*C	0.45	0.37	0.43	2.24	0.18
O	23.6	18.3	13.7	12.6	5.5
Mg	0.2	0.2	-	-	-
Al	1.4	0.8	0.3	0.3	0.2
Si	1.0	0.7	-	-	-
P	1.1	0.7	0.1	1.2	0.1
*S	0.11	0.11	0.15	0.67	0.48
Cl	-	-	-	6.3	19.3
Ca	1.2	0.6	-	0.3	-
Mn	7.4	2.7	0.2	0.1	-
Fe	2.3	1.1	0.2	0.2	0.2
Sn	2.8	3.1	1.4	0.1	2.1
Pb	58.6	71.3	83.6	76.1	72.0

*C and S by combustion

CDM Smith

cdmsmith.com