

**Attachment D –
Results of End-Use Plumbing Components Testing**

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Results of End-Use Plumbing Components Testing

Abstract

The Seattle School Board adopted a policy in 2004 that limits acceptable lead (Pb) levels to 10 µg/L at drinking water sources in Seattle Public Schools. Several possible sources of Pb were identified in school piping systems including brass components and fittings in end-use plumbing. Field and laboratory studies were therefore conducted to determine Pb release from new end-use plumbing components and fittings installed at drinking water sources (primarily fountains) in Seattle Public Schools. Field studies were conducted by collecting sequential small-volume samples at 16 sources in 3 schools to assess the relative contributions of the various end-use components and fittings to lead in drinking water at the tap. Results indicated that most of the lead contained in first-draw 250-mL samples originated in the first 50 mL drawn from the source. Laboratory studies utilized stagnation and flow-through testing procedures on new end-use components and fittings with local tap water to determine Pb release as a function of cumulative contact time. Laboratory results showed elevated Pb levels during early testing, followed by a general decline in Pb levels with repeated exposures attributed to passivation of exposed brass surfaces. Periodic spikes in Pb observed for some components (i.e., bubbler heads and brass shutoff valves) were attributed to the movement of the valves during sample collection and possible release of machining residuals and metal particulates, or dezincification of brass materials. Field and laboratory testing results are significant because new end-use plumbing components typically had been installed in Seattle Public Schools immediately after purchase, without pre-conditioning. Results from this study were used to help identify likely causes of high Pb levels in water samples and develop mitigation measures, such as pre-conditioning of end-use plumbing components, so that drinking water sources can be used immediately after being retrofitted with new components and fittings in Seattle Public Schools.

Introduction

Seattle Public Schools purchases water from Seattle Public Utilities for drinking water, other potable uses, and fire protection service. Seattle Public Schools provides educational opportunities to 47,000 students in 102 schools and administrative buildings. More than 60% of these structures are plumbed primarily with galvanized steel piping, which is over 40 years old and moderately tuberculated. In late 2003, Seattle Public Schools was faced with numerous inquiries associated with the quality of water in its school buildings, with particular concern regarding lead (Pb) exposure to school children from drinking water fountains.

A comprehensive water quality monitoring program of more than 3,000 water sources was conducted in 2004 prior to lead remediation action, which is referred to as Phase I Sampling.

Analyses included lead, cadmium, zinc, copper, iron, turbidity, color, and coliform bacteria. Results indicated that 600 first draw samples out of 3,167 samples (19.0%) exceeded the USEPA's guideline of 20 µg/L Pb in schools based on 250-mL samples that had been standing overnight (15-18 h) in the fountain and connective piping system. Because of the high variability noted in the Pb sampling results, the School Board decided to establish a more stringent criterion for Pb at less than or equal to 10 µg/L in a 250-mL sample collected after standing overnight or in the following 250-mL sample after a 30-second flush at all drinking water sources in Seattle Public Schools (Seattle Public Schools, 2004). As part of the ongoing water quality testing program, remediation strategies have been developed and are being implemented aimed at reducing lead so that levels do not exceed 10 µg/L at all sources in Seattle Public Schools.

Several possible sources of Pb were identified in the school piping systems including old galvanized steel pipe, 50:50 lead:tin solder, and brass components such as bubbler heads, valves, ferrules, and flexible connectors. The brass components may contain up to 8 percent lead (by weight). Several mitigation measures were therefore investigated and applied to a building, depending on the site-specific conditions. Alternative mitigation measures included the following: total or partial replacement of building piping; replacement of bubbler heads with low-lead (<0.3% Pb) brass bubblers; installation of new end-use plastic-lined flexible connectors, valves and fittings; disabling the fountain if there were other accessible fountains nearby; installation of granular-media point-of-use filters for Pb removal from incoming water (Boyd et al., 2005); and/or ongoing provision of bottled water in the schools. One of the more challenging aspects of the investigations included identifying end-use plumbing components that contained little or no Pb and that would not cause Pb levels to exceed the School Board limit of 10 µg/L. Typical replacement components and filter system that have been installed as part of the mitigation program in Seattle public schools are shown in Figure 1.

This paper focuses on a field sampling program and laboratory study aimed at determining Pb release from end-use plumbing components and fixtures in Seattle Public Schools. Field sampling indicated that new end-use plumbing could contribute elevated Pb levels at drinking water sources immediately after installation and periodically during routine usage. Results of laboratory testing were used to assess the contribution of each end-use plumbing component and fitting to Pb levels in first-draw 250-mL samples in Seattle Public Schools. Results of this study also were used to assist in developing a strategy for achieving the water quality goal of not more than 10 µg/L Pb from all sources in Seattle Public Schools.

Materials and Methods

Field sampling and laboratory testing procedures were developed to determine which end-use plumbing components and fittings in Seattle Public Schools were contributing higher-than-expected Pb concentrations in drinking water. Procedures and analytical methods are described below.

Sampling Procedures in Schools

A special “sequential” sampling program was conducted in Seattle Public Schools by collecting several contiguous 50-mL or 100-mL samples from drinking water sources (fountains) after standing stagnant in the end-use plumbing. The sampling program was aimed at identifying which components and fittings in the last few feet of end-use piping were contributing lead to the drinking water source. A total of 22 drinking water sources were tested in 4 schools.

The sampling program was conducted in December 2004 and June 2005. Each source was flushed the day before testing by holding the bubbler valve opened for 2 minutes. Before the start of the school day, samples were collected at each source after allowing contact of standing water from the regular supply with the piping system for approximately 16 hours. Samples were collected from 7 sources in Graham Hill Elementary School (GRH). At each source, eleven 50-mL samples were collected sequentially for a total of 550 mL. Additionally, ten 100-mL samples were collected sequentially, for a total of 1000 mL from each source, at 5 sources in Ingraham High School (IGR) and at 4 sources in Whitman Middle School (WHM). Also, nine 100-mL samples were collected from 6 sources in Schmitz Park Elementary School (SMP).

All 22 drinking water sources were fitted with new “low-lead” or “non-lead” (<0.3% Pb) brass bubbler heads. Point-of-use filters were installed on the tested sources, except for two sources (WHM-06 and IGR-16). Each point-of-use filter installation consisted of an in-line 5- μ m pre-filter and a granular carbon media filter. All point-of-use filter installations were field verified, except for four sources (IGR-02, IGR-06, IGR-19, and WHM-14). The outlet of the point-of-use filter likely was connected with a brass elbow connector (containing up to 8% Pb) at most of the installations.

Laboratory Testing Procedures

New end-use plumbing components and fittings were tested in the HDR Advanced Research and Technology (AR&T) Center in Bellevue, Washington during August to October 2005. End-use plumbing components and fittings included the following: two types of low-lead (<0.3% Pb) bubbler heads, an 18-inch long flexible connector with inside plastic liner and brass ferrules at each end, a brass elbow connector that was used with point-of-use filter installations, and a 1/4-inch brass shut-off valve. The specific end-use plumbing components that were selected for this study were tested because they had been installed as replacement parts and routinely used in Seattle Public Schools since 2004. All components and fixtures used in this study were new parts as purchased from a supplier or off the shelf of a local plumbing shop.

Two procedures were used to test Pb release from the end-use plumbing components and fittings: “stagnation” testing and “flow-through” testing. For the “stagnation” tests, a component or fitting was filled with tap water and allowed to stand undisturbed for a pre-determined period of time (e.g., 2 h). A sample of the exposed water was drawn from the component or fitting and analyzed for total Pb concentration. The remaining water was discarded and the component was refilled with fresh tap water. The entire process was repeated until Pb levels appeared to stabilize with cumulative exposure. The stagnation procedure was used in testing bubbler heads, a shutoff valve, flexible connectors, and brass elbows.

For the “flow-through” tests, two bubbler heads were tested using a flow-through procedure specifically developed for this study. A bubbler head was mounted in the upright position and connected to the tap water source. The valve was held in the opened position and tap water was allowed to flow through the bubbler head at a rate of 0.5 gpm (1.9 L/min). At a pre-determined time, flow was stopped by releasing the bubbler-head valve. Tap water was allowed to stand in contact with the bubbler head for a period of 2 h. Afterwards a sample was drawn by opening the valve and capturing the first 20-35 mL of flow, which was subsequently analyzed for total Pb. The valve was then locked in the opened position and tap water was again allowed to flow uninterrupted through the bubbler head until the sampling process was repeated.

Local municipal drinking water was used as the contact water, which is the same water delivered to Seattle Public Schools locations. Typical water quality is characterized by pH 7.8-8.3, total alkalinity of 20 mg/L as CaCO₃, hardness of 29-30 mg/L as CaCO₃, TOC of 1.0-1.1 mg/L, TDS of 53-58 mg/L, soluble reactive phosphate of 5-6 µg/L, and free chlorine residual of 0.9 mg/L (Seattle Public Utilities, Drinking Water Quality Annual Report, 2004). Background water quality samples were collected periodically at the tap in the HDR AR&T Center. Analyses of background water samples consistently yielded total Pb levels less than 1 µg/L.

Sample Collection and Analytical Methods

All field and laboratory samples were collected in new 250-mL polypropylene bottles, stored in a laboratory refrigerator, transported to Laucks Testing Laboratories, Inc. in Seattle, Washington, and analyzed for total Pb within 2-14 days. All samples were acidified upon receipt at Laucks to preserve the samples. All analyses followed EPA-600/4-79-020 Method 200.8, for which Laucks holds accreditation through the Washington State Department of Ecology. Samples were analyzed using inductively coupled plasma mass spectrometry (Perkin Elmer ELAN 6100 or Agilent 7500c) with a detection limit of 1 µg/L.

Sample volumes that were less than 50 mL were diluted at Laucks Testing Laboratories to a final volume of 50 mL for total Pb analysis, thus yielding a detection limit that varied depending on the amount of sample submitted. For sample volumes between 10 and 50 mL, the detection limit was 5 µg/L. Sample volumes that were less than 10 mL were similarly diluted and therefore yielded a detection limit of greater than 5 µg/L (up to 200 µg/L). Quality control protocols included chain-of-custody, sample preparation and analysis, data processing and review, as well as preparation and analysis of quality control samples for assurance of accurate and precise measurements.

Results and Discussion

Field sampling and laboratory testing data are summarized below. Field and laboratory results were used to assess the relative contribution of end-use plumbing components and fittings to the total Pb level in a first-draw 250-mL sample collected at a source, as discussed below.

Field Sampling Results

Field sampling results are shown in Figure 2a for 50-mL samples collected at Graham Hill Elementary School. Five of the sources at Graham Hill School (GRH-01, GRH-03, GRH-13, GRH-14, and GRH-18) exhibited Pb levels in the first 50-mL sample that ranged from 38-79 µg/L. The Pb concentration in the first sample was significantly greater than the subsequent samples collected from these five sources. The relative Pb concentration of sequential samples collected from each source is illustrated in Figure 2b, which shows the field data normalized relative to the second sample collected at each tested source in Graham Hill School. The other 2 sources (GRH-11 and GRH-19) exhibited Pb levels in the first and second 50-mL sample in the range of 9-15 µg/L, whereas subsequent samples from each of these sources were at or near the detection limit in the range of <1-4 µg/L. These results indicate that components and fittings near the exposed end of the source (i.e., bubbler head, connectors, and connective tubing) likely contributed to elevated Pb levels at all seven of the sources at Graham Hill School. It was therefore recommended that additional testing be conducted on the new “low-lead” bubbler head, connectors, and connective tubing to determine the level of lead release associated with these components and fittings.

Data in Figure 2 also show an increasing trend in Pb levels at Graham Hill School beginning with the 4th or 5th sequential sample (cumulative volume of 200-250 mL), with most profiles peaking in the 6th sequential sample (cumulative volume of 300 mL). These results indicate that another component or fitting likely contributed as a source of lead, and it was estimated to be situated approximately 4 ft extending back from the bubbler head along the end-use plumbing (assuming ½-inch ID piping). This secondary source of lead was suspected to be contributed by brass elbow connectors (containing up to 8% Pb), which were routinely being used at the outlet of the point-of-use filter installations in Seattle Public Schools. It was therefore recommended that additional testing be conducted to determine the level of lead release associated with these fittings.

Figure 3 shows results for 100-mL samples collected at Ingraham High School. Elevated Pb levels were observed in the first 100-mL samples collected at 4 of the 5 sources (IGR-02 was the exception). Similar to Graham Hill School, the first samples collected at most sources in Ingraham High School indicate that components and fittings near the exposed end of the source likely contributed lead to the water supply. Elevated Pb levels also were observed in the 3rd or 4th 100-ml samples (cumulative volume of 300-400 mL), which is consistent with observations of elevated Pb levels associated with the same cumulative volume of drawn water at Graham Hill School. However, at Ingraham High School the magnitude of the secondary Pb concentration was not as pronounced as observed by collecting 50-mL samples at Graham Hill School. Nonetheless, these results indicate that secondary sources (e.g., brass in components or fittings) likely contributed to elevated Pb levels in most sources at Ingraham High School.

Figure 4 shows results for 100-mL samples collected at Whitman Middle School. For samples collected at this school, only 1 out of the total of 4 sources (WHM-9) exhibited a markedly greater Pb concentration in the first 100-mL sample compared to the following samples. These data indicate that the end-use plumbing at the exposed end of the source likely did not contain fittings or components that were releasing elevated levels of Pb to the water supply. Two of these

sources (WHM-06 and WHM-14) exhibited a weak peaking trend in subsequent samples, which likely indicates a secondary source of lead.

Figure 5 shows results for 100-mL samples collected at Schmitz Park Elementary School. Results from this school generally are consistent with other field results in that the data show elevated Pb levels in the initial samples, followed by a decline and then increasing trend in Pb in later sequential samples. Again, these results indicate that the source likely contained a fitting or components with lead-bearing material at the exposed end and at another location along the stretch of the end-use plumbing at the sampling sites in this school.

Laboratory Testing Results

Pb concentrations are shown in Figure 6 for two types of low-lead bubbler heads typically installed at drinking water fountains in Seattle Public Schools. Results of “flow-through” testing on one of each type of bubbler head (identified as Type A and Type B) are shown as a function of cumulative exposure to tap water in Figure 6a. Results of “stagnation” testing using one type of bubbler head (identified as Type A) are shown in quadruplicate in Figure 6b. Both testing procedures yielded elevated Pb levels (33-60 ppb) during initial exposure for both types of bubbler heads. Stagnation testing exhibited periodic spikes in Pb up to 1,300 µg/L for a cumulative exposure period of nearly 200 hours. Flushing and repeated exposure to tap water reduced Pb levels with time and the data generally appeared to approach stabilized lead levels near the detection limit of 5 µg/L at the end of testing.

Pb results for a brass shutoff valve commonly used in Seattle Public Schools are shown in Figure 7. The shutoff valve was tested in quadruplicate. Results of stagnation testing indicate elevated Pb levels up to 500 µg/L during initial exposure. Some Pb fluctuations and spikes were observed during testing. Due to the small volume of water contained within the valve (~2 mL), the analytical detection limit was 50 µg/L for samples collected during stagnation testing of this valve. Overall, Pb levels declined with repeated exposure to a range of 50-80 µg/L after a cumulative exposure of 343 h.

Pb results are shown as a function of cumulative exposure to tap water in Figure 8 for a flexible connector (18-inch length). This component does not contain a mechanical moving part such as a valve. The specimen was tested in triplicate using the stagnation procedure. Results shown in Figure 8a indicate elevated Pb levels (68-250 µg/L) during initial exposure time and a gradual decline to 9-29 µg/L after nearly 23 days of cumulative exposure to tap water. The source of lead was attributed to the brass ferrules at both ends of the flexible connector, as shown in Figure 8c.

Pb results are shown in Figure 9 for brass-elbow-connector units as a function of cumulative exposure to tap water. Each test unit was assembled by connecting three brass elbows in series with plastic couplings. The units were assembled for the purpose of allowing sufficient volume of tap water in contact with the inside of the component. Unit testing was conducted in quadruplicate. Results indicate elevated Pb levels in the range of 770-1,100 µg/L following contact for up to 24 h. With repeated exposures, the lead levels showed some variability and generally declined to the range of 220-360 µg/L after approximately 6 days of exposure to tap water.

Discussion of Results

Sequential sampling conducted at representative drinking water sources in Seattle Public Schools indicated that various end-use plumbing components and fittings could contribute elevated Pb levels to the water supply after standing stagnant overnight. Results showed elevated Pb concentrations in the first and second samples, thus indicating a release of lead likely originating from the bubbler head or associated fittings and components. In addition, results frequently showed a gradual increase in Pb levels, a secondary peak, and gradual decline in Pb concentrations in subsequent samples, thus indicating the likelihood of another component or components in the end-use plumbing contributing Pb to the water supply. This secondary contributor was determined to be various components consisting of lead-bearing materials such as brass. The gradual increasing and declining trends in Pb levels observed in sequential samples were attributed to diffusion of lead from the point of release (e.g., lead-bearing materials) into the standing water during the stagnation periods.

Laboratory testing results demonstrated that new fittings and components containing lead-bearing materials (e.g., standard brass elbows or brass ferrules) can exhibit elevated Pb levels in testing immediately after installation, followed by a general decline in Pb levels with repeated tap water exposures. Initial elevated Pb levels could be attributed to contact of water with unpassivated lead-bearing materials and/or the release of machining residuals (ASTM A380-99, 2005). The declining behavior of Pb concentration with time following contact with lead-bearing materials has been observed by others (e.g., Schock, 1990) and attributed to passivation of exposed brass surfaces. For the testing results reported here, the passivation period was observed to extend up to 200 hours or longer, depending on the specific materials and contact time.

The greatest initial Pb concentration was observed in water exposed to standard brass specimens (~8% Pb by weight) compared to new low-lead or non-lead brass materials. For example, the initial Pb levels associated with the brass shutoff valves (Figure 7) and elbow connectors (Figure 9) were generally greater than the initial Pb levels in the bubbler heads (Figure 6). The bubbler heads that were tested in this study were reportedly made of new low-lead or non-lead brass materials and the initial Pb levels were observed to be correspondingly lower than standard brass materials.

Laboratory testing demonstrated that brass-containing fittings and components with mechanical parts (e.g., bubbler heads and shutoff valves) exhibited periodic spikes in Pb. These periodic spikes were not as evident in the other tested components (i.e., connective tubing and elbow connectors). The spikes in Pb were attributed to the possible release of particulates associated with the release and turning of valves. In a separate study for Seattle Public Schools, Boyd et al. (2006) determined that the greatest variability in Pb concentration was attributed primarily to dezincification of lead-containing brass materials. 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 (Schock, 1990; Davies, 1993; Grosvenor et al., 2005). For non-lead brasses that contain bismuth (Bi) as a substitute for Pb, the Bi-containing non-lead brasses can be more susceptible to dezincification than standard lead brass (Kim et al., 2001). The variability in Pb levels observed in some drinking water sources in Seattle Public Schools (Figures 2 through 5) could therefore be attributed to the

release of particulates associated with the movement of mechanical parts, or the dezincification process, during testing or routine use.

Estimated Pb Contributions of Components and Fixtures

Table 1 was prepared to evaluate the potential impact of an individual component or fitting to Pb levels at the tap. The calculations are based on the estimated volume of exposed water in contact with the component or fitting, and the concentration of Pb measured in laboratory testing (Figures 6 through 9). Two scenarios are illustrated in Table 1. The “worst case” scenario is based on data collected during initial testing and the “typical” scenario is based on Pb levels measured near the end of the testing period. For each component or fitting, the mass of Pb was calculated and then divided by 250 mL to provide an estimate of the contribution of the individual component or fitting in the first-draw 250-ml sample collected from the source. The estimated Pb concentration in a 250-mL sample, assuming each individual component or fitting is the only contributor of lead, is shown in the last 2 columns of Table 1 for the worst case and typical scenarios.

The components with the greatest potential for contributing elevated Pb levels were the plastic-lined flexible connector with brass ferrules at the ends and the brass elbow. Either of these components could easily have caused a first-draw 250-mL sample to exceed the 10 µg/L Pb limit as established by Seattle School Board policy. Further, laboratory results indicate that Pb contributions from several of these end-use plumbing components can result in elevated Pb levels, particularly when these components have not been previously exposed to water. It was also interesting that small amounts of Pb were contributed by the new stainless steel bubbler head attributed to surface impurities. Laboratory and field testing indicated that these residuals can be easily removed by flushing.

Conclusions

Laboratory and field studies were conducted to determine the influence of end-use plumbing components on Pb levels in drinking water in Seattle Public Schools. The Seattle School Board adopted a policy in 2004 that limits acceptable lead levels to 10 µg/L. Sequential, small-volume samples were collected at several bubbler installations in schools and analyzed for Pb. Results were used to help identify the relative contribution of the various end-use components and fittings to Pb levels at the tap. In addition, laboratory testing was conducted on flexible connectors, brass fittings, valves, and low-leaded brass bubbler heads to evaluate potential Pb release from fittings and components that were commonly used in Seattle Public Schools. Results were used to estimate the relative contribution of each fitting and component to the total Pb level in a 250-mL sample. Results from these studies were used to identify specific, commonly-available end-use plumbing components and materials that provide the best performance for achieving Pb standards in Seattle Public Schools.

This applied research effort helps Seattle Public Schools in several ways. It helps identify the likely causes of high Pb levels in water in new installations so solutions can be implemented immediately. Different components that do not contribute lead, or contribute minimally, were specified. Bubbler heads are being preconditioned by Seattle Public Schools before installation.

After installation, a major flushing program takes place in the schools. Each drinking water source is then sampled and results must meet the Board's water quality criteria before returning the source to service in the school.

References

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Table 1. Estimated range of lead contributions from end-use plumbing components.

Component or Fitting	Exposed Volume (mL)	Laboratory Measured Pb ($\mu\text{g/L}$) ^{a,b}		Calculated Mass of Pb (μg)		Estimated Pb Concentration in 250-mL Sample ($\mu\text{g/L}$) ^c	
		Worst Case	Typical	Worst Case	Typical	Worst Case	Typical
Brass bubbler head w/ stainless steel nipple (Type A)	10	60	10	0.6	0.1	2.4	0.4
Stainless steel bubbler head (Type B)	1.3	33	10	0.04	0.01	0.17	0.05
Flex connector w/ brass ferrule ends, 18" long	33	250	15	8.25	0.5	33	1.98
Brass elbow connector	3	1400	200	4.2	0.6	16.8	2.4
Brass shut-off valve	2	500	100	1.0	0.2	4.0	0.8

Notes: a) Sample concentrations are based on measured values in the exposed volume from laboratory testing.

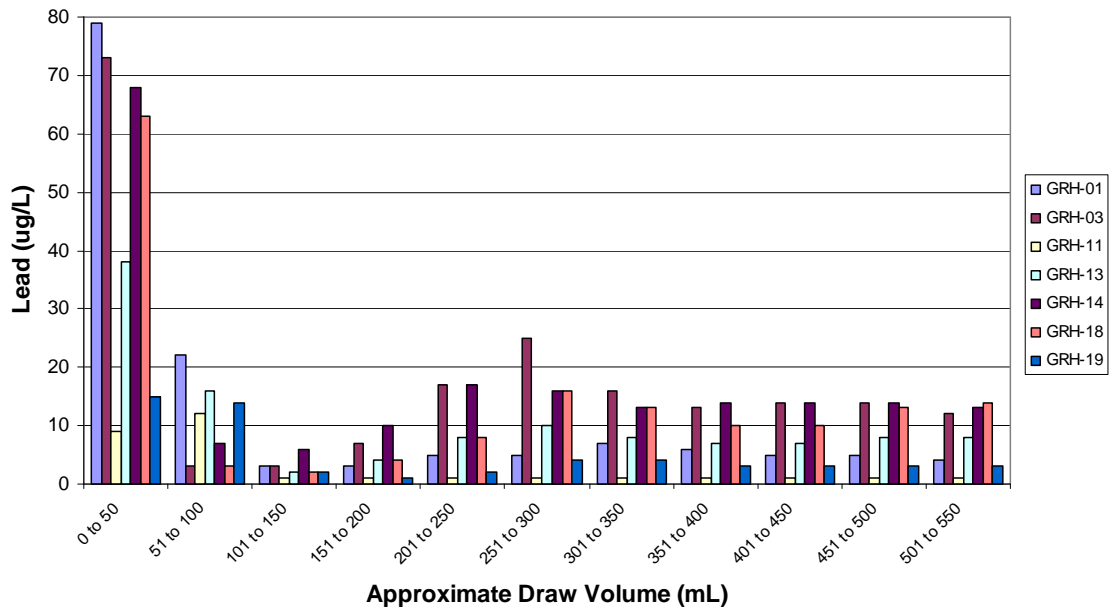
b) Analytical detection limit was 5 $\mu\text{g/L}$.

c) Assumes that the resulting Pb concentration in a 250-mL sample is estimated from data for that particular component only, where the concentration in a 250-mL sample = (exposed volume) \times (measured Pb concentration in exposed volume) / (250).



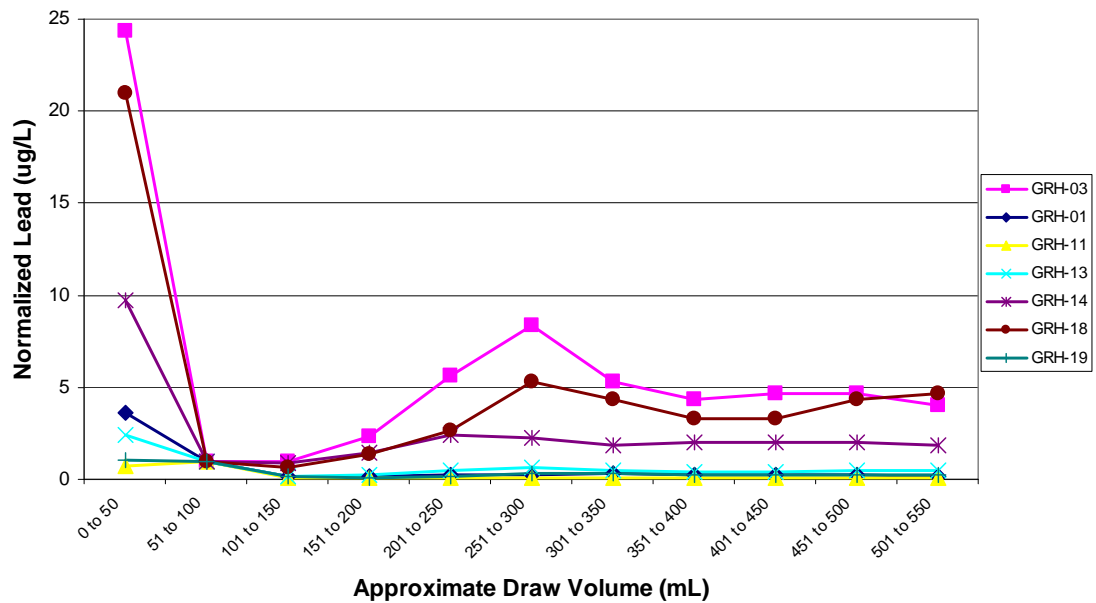
Figure 1. Typical older drinking water fountain installation in Seattle Public Schools showing (a) shut off valve and connective piping and (b) bubbler head and sink. Typical newer drinking water fountain installations showing (c) flexible connective piping with brass ferrule ends, (d) granular-media filter system with flexible connective piping with brass fittings, (e) filter system with plastic fittings and tubing downstream of filter, and (f) low-lead (<0.3% Pb) bubbler head and sink.

Graham Hill Elementary School - Segmented Sampling Results
(50 mL Samples)



(a)

Graham Hill Elementary School - Segmented Sampling Results
(50 mL Samples)



(b)

Figure 2. Segmented field sampling results for Graham Hill Elementary School: (a) sampling data as collected and (b) normalized data.

**Ingraham High School - Segmented Sampling Results
(100 mL Samples)**

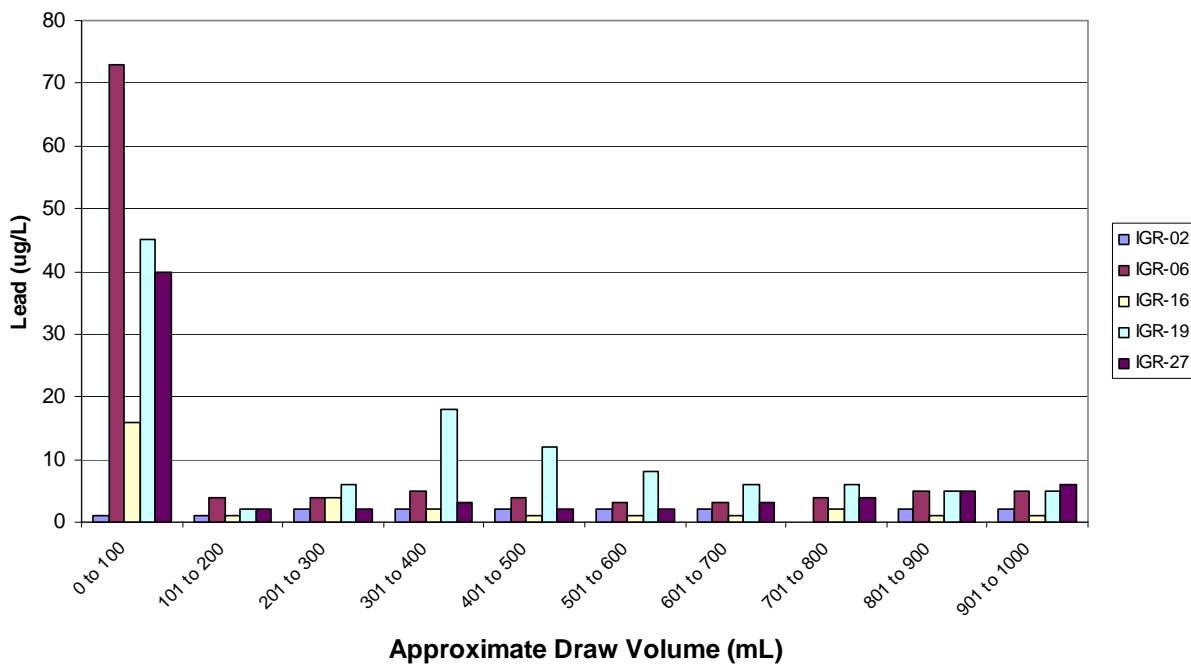


Figure 3. Segmented field sampling results for Ingraham High School.

**Whitman Middle School - Segmented Sampling Results
(100 mL Samples)**

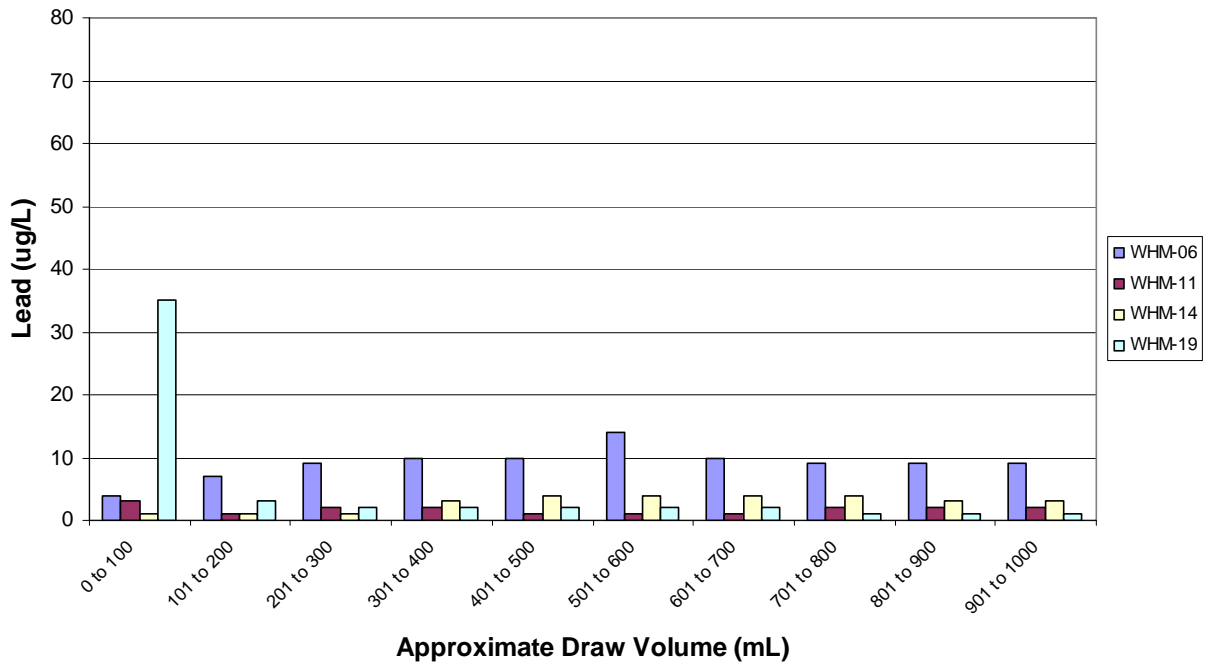


Figure 4. Segmented field sampling results for Whitman Middle School.

**Schmitz Park Elementary School - Segmented Sampling Results
(100 mL Samples)**

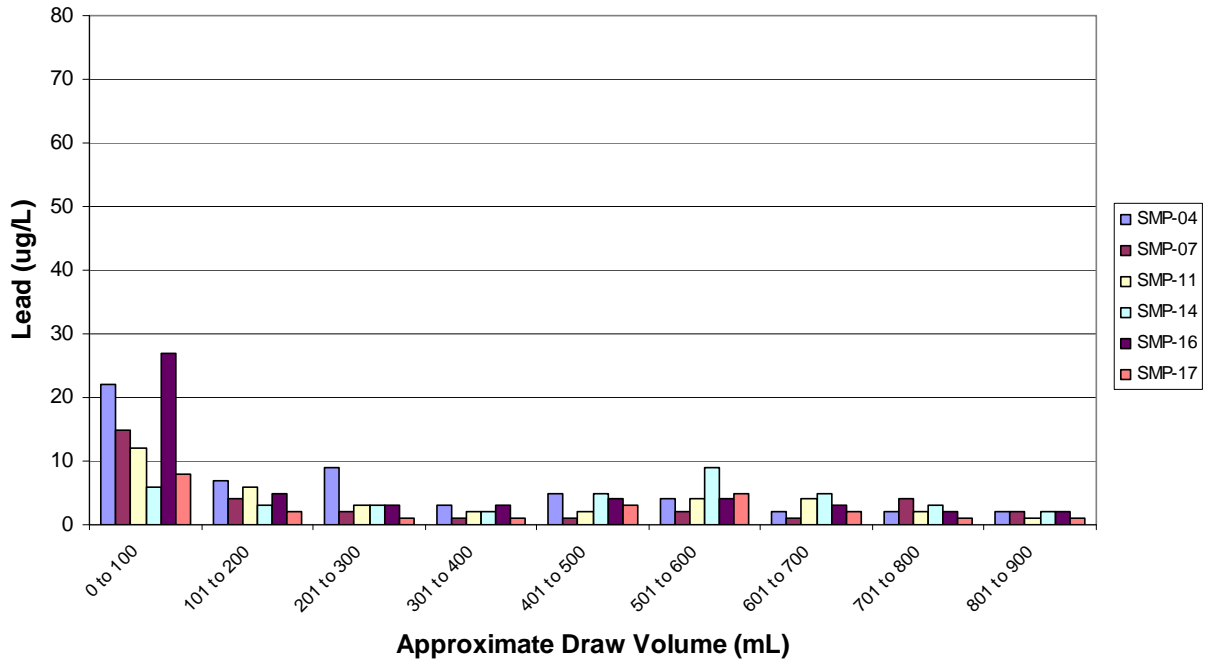


Figure 5. Segmented field sampling results for School E-2.

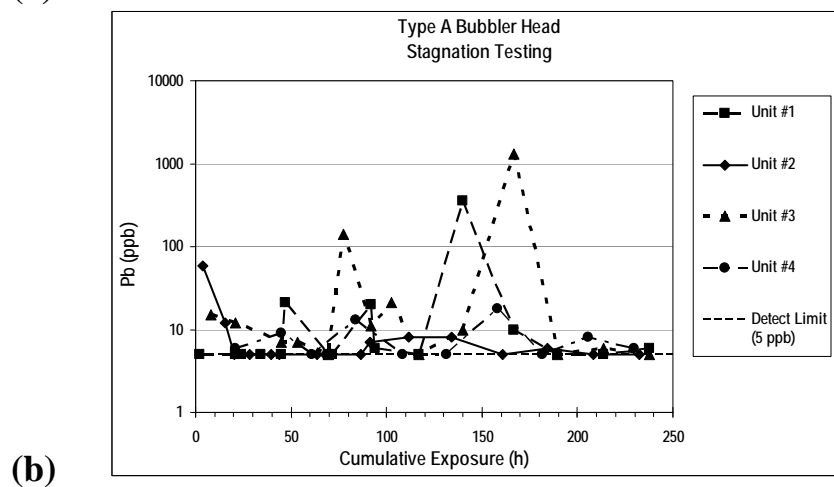
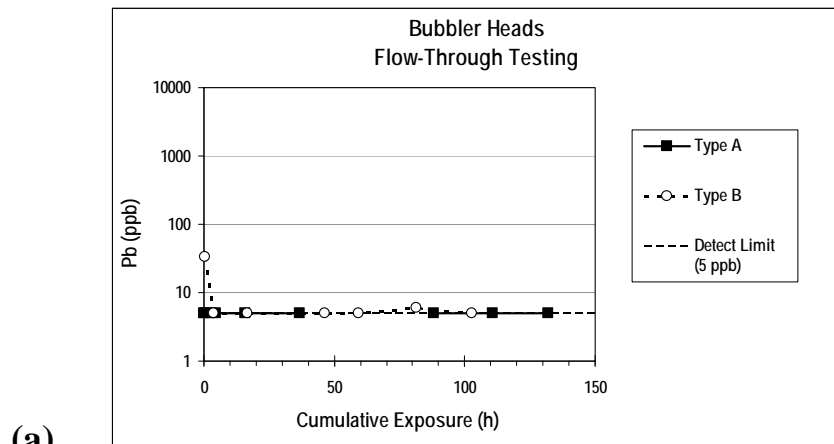
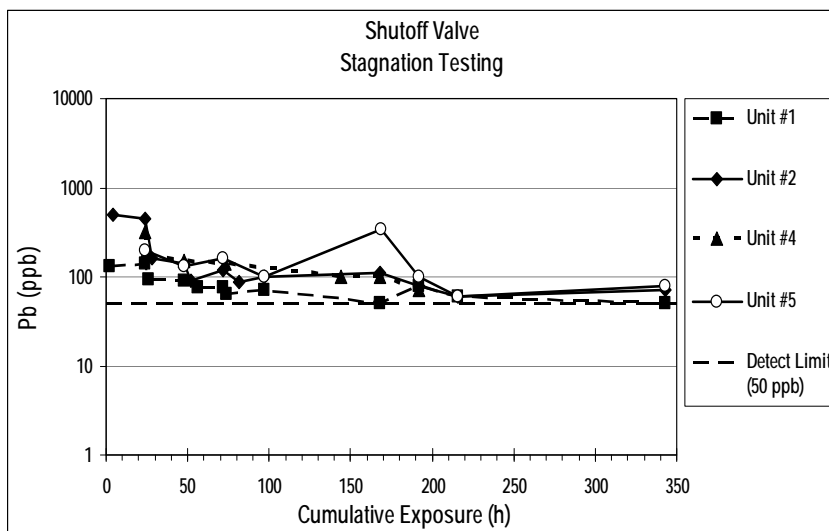


Figure 6. Pb concentration in tap water as a function of cumulative exposure of bubbler heads to tap water during (a) flow-through testing and (b) stagnation testing. (c) Bubbler head with valve held opened during flow-through testing.



(a)



(b)

Figure 7. (a) Pb concentration in tap water as a function of cumulative exposure and (b) a type of brass shutoff valve used in Seattle Public Schools and tested in this study.

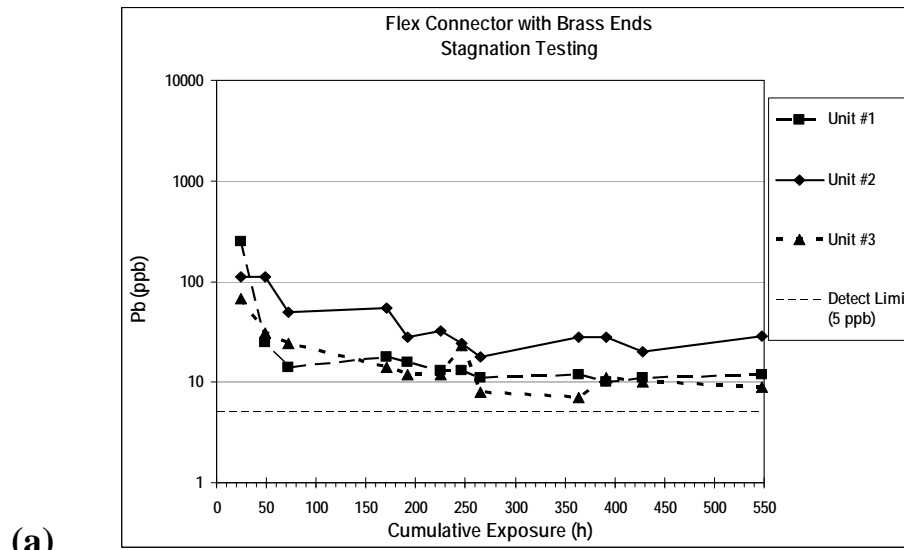
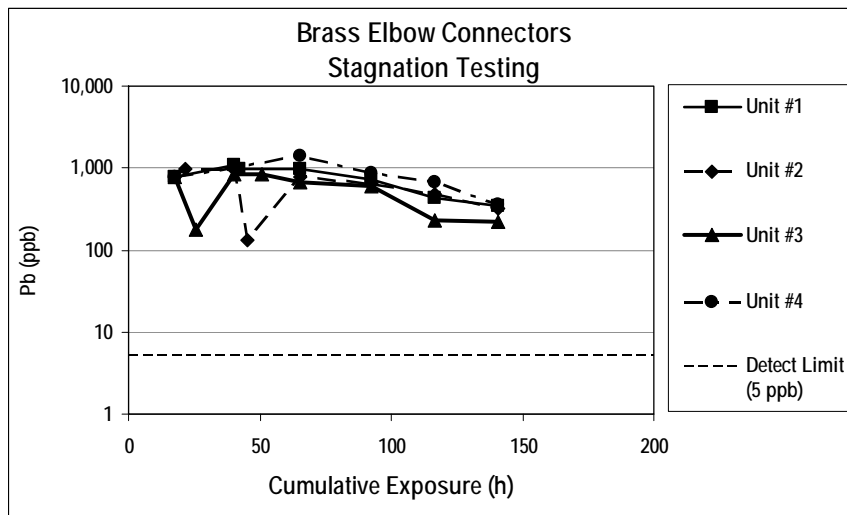


Figure 8. Stagnation testing in triplicate of a flexible connector with brass ferrules at both ends. (a) Pb concentration in tap water as a function of cumulative exposure time, (b) specimens prepared for testing, and (c) enlarged view of brass ferrule at one end of flexible connector.



(a)



(b)

Figure 9. Stagnation testing in quadruplicate of three brass elbows linked together (a) Pb concentration in tap water as a function of cumulative exposure to tap water and (b) specimens prepared for testing.