# Attachment R.6 -
# Lead Variability Testing in Seattle Public Schools.
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# Lead Variability Testing in Seattle Public Schools

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## ABSTRACT

A field testing program was conducted in Seattle Public Schools to assess the variability of lead (Pb) at drinking water sources after implementing a lead remediation program. Four configurations were identified as typical end-use plumbing. Twelve drinking water sources were selected based on statistical correlations to represent each configuration. Eight days of sampling (both first draw and flushed samples) were collected from each source after overnight standing. Results indicate that 12 samples out of a total of 768 (1.6%) exhibited Pb >10 μg/L, 4 samples (0.5%) exhibited Pb >20 μg/L, and none were greater than 30 μg/L. The highest Pb levels and greatest variability occurred in samples from configurations with standard brass materials (up to 8% Pb). Relatively low Pb concentrations and variability were observed for sources with low-lead bubblers and new components. The mean concentration of Pb for all samples was 2.8 μg/L compared to 20.8 μg/L before remediation.

# INTRODUCTION

Sources of lead in drinking water in Seattle Public Schools include old galvanized piping, lead/tin solder, and brass materials in plumbing components and fittings. Lead is present in plumbing materials in the form of elemental Pb. In alloyed materials such as brasses used in faucets, lead is interspersed with other elements (e.g., copper and zinc) throughout the alloy matrix. When the alloyed material comes in contact with potable water, the lead becomes oxidized, enabling mobilization and subsequent transport of lead into the drinking water supply.

Lead levels in tap water depend on a variety of site-specific conditions including solubility factors (i.e., water quality characteristics) and physical factors (e.g., nature and age of plumbing surfaces). An analysis of published data by Schock (1990) showed that the variability of lead is characterized by the frequent occurrence of ‘spikes’. Schock (1990) compared results of lead studies conducted in Boston, Massachusetts and Glasgow, Scotland before and after implementing corrosion control treatment in the distribution system. While the mean lead levels were generally lower after treatment, Schock (1990) concluded that the standard deviation in these field studies were similar in the range of 0.6 to 1 times the mean lead concentration.

According to Schock (1990), the variability of lead in tap water samples should be determined for each site and system by conducting a site-specific sampling program. Kirmeyer et al. (2004) provided guidelines for developing a statistically valid sampling program for determining lead concentrations in tap water. The guidelines provide a method for estimating the number of samples required and the frequency of collection based on an estimation of the variability of lead and the desired significance and accuracy of the data. These guidelines were used to develop the sampling program and evaluate field data for lead variability testing in Seattle Public Schools.

## BACKGROUND AND OBJECTIVE

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. Chemical analyses included lead, cadmium, zinc, copper, iron, turbidity, color, and coliform bacteria. Results (Table 1) 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 (Seattle Public Schools, 2004). As part of the ongoing water quality testing program, remediation strategies are being developed and implemented aimed at reducing lead so that levels do not exceed 10 µg/L at all sources in Seattle Public Schools.

The objective of this study was to develop and implement a sampling program to assess the variability of lead levels at drinking water sources (fountains) in Seattle Public Schools. The testing program was designed to provide statistically meaningful data for common types of end-use plumbing configurations in Seattle Public Schools. Results were used to compare the average (mean) lead concentration and standard deviation for each type of plumbing configuration, and to assess the accuracy and confidence level of lead data collected at drinking water sources in Seattle Public Schools.

## MATERIALS AND METHODS

Local municipal drinking water is delivered to drinking water sources in Seattle Public Schools. Typically the municipal water quality is characterized by pH 7.8-8.7, total alkalinity of 20 mg/L as $CaCO_3$, hardness of 29-30 mg/L as $CaCO_3$, TOC of 0.7-1.5 mg/L, and free chlorine residual of 0.9 mg/L (Seattle Public Utilities, Drinking Water Quality Annual Report, 2004). All samples were collected in 250-ml polypropylene bottles, stored on ice, transported with chain-of-custody forms to North Creek Analytical, Inc. in Bothell, Washington, and analyzed for total Pb within 7 days. Total Pb analysis was conducted by EPA Method 200.8 with a method detection limit of 0.02 μg/L.

**Classification of end-use plumbing configurations.** Four types of end-use plumbing configurations were identified as common installations in Seattle Public Schools. For the purpose of this study, end-use plumbing is defined as those plumbing components starting with the shut-off or stop valve to an individual sink or drinking water fixture up to and including the faucet or bubbler fitting itself. This definition includes any in-line point-of-use (POU) filter, pre-filter and associated fittings. End-use plumbing does not include the connecting pipe that extends back from the shut-off valve through the wall or floor to a building supply pipe.

The four common types of end-use plumbing configurations in Seattle Public Schools are shown in Figure 1. There is a total of approximately 3,600 sources (fountains) in 117 buildings (schools and related facilities). Type A configuration is characterized by all older end-use plumbing components (bubbler head, connective piping, and shut-off valve), including fittings and components made of standard brasses containing up to 8% Pb (EES and ISWS, 1990; Lytle and Schock, 1996).

Type B configurations consist of a new “low-lead” or “non-leaded” (<0.3% Pb) brass bubbler head, a standard 18-inch (46-cm) long flexible connector, and a standard shut-off valve. The 1996 amendment to the 1986 (U.S.) Safe Drinking Water Act provided an impetus to identify a substitute for lead in cast brasses used in potable water systems. Manufacturers currently offer plumbing components made with these new low-lead brasses (Michels, 2006). All components of the Type B configuration were newly installed within the last year. Types A and B are the most common configurations and represent approximately 88% of end-use plumbing at drinking water sources in Seattle Public Schools. The remaining 12% of plumbing configurations are characterized as Types C and D configurations.

Type C is characterized by a new low-lead or non-leaded brass (<0.3% Pb) bubbler head and a 12- to 36-inch (30- to 91-cm) long flexible connector to the POU filter system. The POU filter system consists of an in-line pre-filter and filter[1] with a brass elbow connector (up to 8% Pb) at the outlet of the filter. Type C configuration also has a standard 12- to 36-inch (30- to 91-cm) flexible connector between the filter components and the shut-off valve. All of these Type C components were newly installed within the year prior to conducting the variability study.

Similar to Type C, the Type D configuration consists of a new low-lead or non-leaded brass (<0.3% Pb) bubbler head and an in-line POU filter system with standard 12- to 36-inch (30- to 91-cm) flexible connectors between the filter components and the standard shut-off valve. However, the Type D configuration is different in that the elbow at the filter outlet and connective piping from the filter to the bubbler head are made of polymeric materials. All of the Type D materials were similarly installed as new components within the past year.

**Statistical methods and evaluation criteria.** Statistical methods were used to determine a suitable number of sources that were tested for each type of plumbing configuration in Seattle Public Schools. Kirmeyer et al. (2004) used the coefficient of variation (*CV*) to assess the variability of Pb concentration at sink taps,

Coefficient of variation $$CV = \frac{S_N}{\overline{X}}$$

Standard deviation $$S_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \overline{X}\right)^2}$$

Average (mean) $$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

where $N$ = number of data points for the variable $x_i$. The coefficient of variation is a measure of the variability of a data set and defined as the ratio of the standard deviation, $S_N$, to the average or mean, $\overline{X}$, of a sample population. Kirmeyer et al. (2004) reported typical values of *CV* in the range of 0.1 to 2.0 for Pb levels in first draw 1-liter samples at sink taps based on extensive lead monitoring data from 11 case studies at public water systems. These monitoring data were evaluated with regard to the level of accuracy and level of confidence in the sample population. Kirmeyer et al. (2004) used the results to develop a series of tables that provides an estimate of the sample size for various *CV*s (0.1-2.0) and corresponding levels of accuracy (5-50%) and confidence (80-95%). The statistical probability of the data can be determined based on a "normal" distribution of results, as represented by the levels of confidence and accuracy. A lower *CV* for a given sample pool size indicates a greater level of statistical confidence and/or accuracy. Conversely, a higher *CV* indicates greater variability. Selected information from these tables is summarized in Table 2.

For this study, the data in Table 2 were used to estimate the number of sources to be tested in Seattle Public Schools to determine the mean Pb concentration for each type of plumbing configuration. A *CV* value of 0.4 was assumed to be a good first estimate based on Kirmeyer et al. (2004). By further choosing a desired accuracy of 15% and a confidence level of 80%, the data in Table 2 were used to estimate that 12 sources (fountains) were needed to determine a representative mean Pb concentration for each type of plumbing configuration. This estimate was used in developing the variability testing program in Seattle Public Schools.

**Sampling procedures.** For each type of end-use plumbing configuration, samples were collected from 12 selected drinking water sources, for a total of 48 sources located in 10 different schools. Samples were collected from each source on 8 separate sampling days to characterize the variability of lead. Sampling occurred during 2 separate one-week periods with flushing on Monday followed by 4 consecutive days of sampling from the same source. Each source was flushed on Monday by holding the bubbler valve opened for 2 minutes. Beginning on Tuesday morning before the start of school, samples were collected at the source after allowing contact of the water supply with the piping system for at least 8 hours but not more than 18 hours per EPA's guidance for collecting samples in schools (USEPA, 2005). Two samples were collected daily by drawing 1) a first-draw 250-mL sample after an overnight stagnant period followed by 2) a 250-mL sample after 30 seconds of flushing.

The total number of samples from each type of plumbing configuration was 192 (12 sources × 8 sampling days × 2 samples per sampling day). The total number of samples collected for this lead variability study was therefore 768 (4 types of plumbing configurations × 192 samples per type of configuration).

## Results and Discussion

The number of test sources by school and type of plumbing configuration is summarized in Table 3. Types A and B configurations were characterized by standard connective piping from the bubbler to the shutoff valve whereas Types C and D were characterized by the installation of a POU filter system at the source. Samples were collected from December 5, 2005 through February 3, 2006.

Results of this lead variability sampling program are shown in Figures 2 through 6 and summarized in Table 4. Total Pb concentrations are reported for both first-draw and 30-sec flushed samples by type of end-use plumbing configuration. Only sources that met the lead water quality criterion of less than 10 μg/L (Seattle Public Schools, 2004) in previous testing were included in this special testing program. The results summarized in Table 4 are based on 8 first-draw samples and 8 flushed samples collected at each drinking water source. The mean lead concentration, standard deviation, and coefficient of variation of the lead data were calculated based on samples collected from each type of plumbing configuration. The data were further evaluated to determine the highest Pb concentration and the number of samples that exceeded the water quality criterion of 10 μg/L.

In Figures 2 through 5, the data shown with a diamond symbol represent the most recent Pb concentration measured at the source as of December 2005. This value was used to determine if water from the source met the drinking water criterion of less than or equal to 10 μg/L for lead. The bold vertical line shown for each source represents the upper and lower limits of the range of Pb concentrations measured during this special study. The symmetrical box represents the boundaries of the standard deviation about the mean Pb concentration. The mean Pb concentration is shown as a horizontal line in the center of the box. A legend, which explains the symbols used in this study, is included in Figure 2 through 5.

**Type A plumbing configuration results.** Pb concentrations are shown by source in Figure 2 for first-draw and flushed samples collected from Type A plumbing configurations. Results indicate that all of the Type A sources exhibited lead concentrations less than 10 μg/L, except for source No. 11 at Leschi Elementary (LSH-11). The first-draw samples collected during this study at LSH-11 ranged from 7.93 to 19.2 μg/L and yielded a mean lead concentration of 11.2 μg/L. In contrast, the flushed samples collected for this study at LSH-11 were all less than 2.5 μg/L. These data indicate that lead was released to standing water in plumbing at this source within approximately 6.5 ft (2 m) of piping from the drinking water fitting, assuming an inside diameter of 0.5 inch (12.7 mm) for the end-use piping.

For the 11 other sources, the first-draw samples exhibited a mean lead concentration and standard deviation of 3.24±1.99 μg/L whereas the flushed samples yielded a mean concentration of 1.74±1.26 μg/L. Even at double the standard deviation, the level is below 10 μg/L; thus, 95% of predicted results, even with the older fittings, are below 10 μg/L. These results demonstrate remarkable consistency in exhibiting lead levels less than 10 μg/L following remediation. Sources therefore generally can be expected to continue meeting the acceptable criterion for lead in Seattle Public Schools.

**Type B plumbing configuration results.** Pb concentrations are shown by source in Figure 3 for the Type B plumbing configuration. Results indicate that all of these sources exhibited lead concentrations less than 6 μg/L in first draw samples, and less than 3.5 μg/L in flushed samples. As summarized in Table 4, the mean lead concentration in both first draw and flushed samples were lower in the Type B configuration compared to Type A. Similarly, the highest Pb concentration and the number of samples that exceeded 10 μg/L were greater for Type A compared to Type B configurations. As illustrated in Figure 1, the Type B configuration was characterized by use of new low-lead brass fittings and components. The new low-lead brass materials reduce the amount of lead in contact with standing water in the plumbing. These results therefore demonstrate that the use of low-lead brass materials can successfully reduce lead levels in drinking water in Seattle Public Schools.

**Type C plumbing configuration results.** Pb concentrations are shown by source in Figure 4 for samples collected at sources characterized as the Type C configuration. Results indicate that all of these sources exhibited lead concentrations less than 10 μg/L, except for source No. 3 at Sacajawea Elementary School (SCJ-03). The first-draw samples collected at this source ranged from 3.29 to 29.1 μg/L and yielded a mean lead concentration of 15.5 μg/L. In contrast, the flushed samples collected at SCJ-03 were all less than 3.5 μg/L.

During the first sampling week, the POU systems at Broadview Thompson (BDT) contained Z-brand filter cartridges. Before the second sampling week, the filter cartridges were replaced with new Y-brand cartridges. All other Type C sources used for this study contained Z-brand cartridges for both the first and second sampling weeks. Further, all of the Type C sources exhibited iron levels less than 0.1 mg/L (Table 3). Thus, the specific brand of filter cartridge contained in the POU system at each source and the iron levels at the test schools did not appear to influence the Pb sampling results for the Type C configuration in this special variability study.

**Type D plumbing configuration results.** Pb concentrations are shown by source for the Type D plumbing configuration in Figure 5. Results indicate that all of the Type D sources exhibited lead concentrations less than 4.5 μg/L in first draw samples, and less than 8 μg/L in flushed samples except for one sample collected from source No. 3 at Van Asselt (VNA-03) at 11 μg/L. By comparing the statistical parameters of Type C and Type D configurations (Table 4), results indicate that the first draw samples of Type C configuration exhibited greater lead concentrations and greater lead variability than the Type D configuration. These results demonstrate that the use of plastic fittings instead of brass elbows between the filter effluent and the bubbler head reduced the overall level of lead in the drinking water supply in Seattle Public Schools.

During both sampling weeks, approximately half of the Type D sources contained Z-brand cartridges and the remaining POU filter systems contained Y-brand cartridges (Table 3). Four of the sources included in this variability testing program (RGS-02, RGS-05, SCJ-09, and

VNA-03) contained the Z-brand cartridge. These four sources exhibited the greatest variability in the flushed samples. However, it should be noted that the mean lead concentrations of all sources with POU filter systems (Types C and D) were less than 10 μg/L and the maximum lead concentration in flushed samples was 11 μg/L.

As part of previous studies for Seattle Public Schools (Boyd et al., 2005), POU filtration units were installed and sampled in selected schools to determine the effectiveness of the units for removing lead, iron and other contaminants. The principal operating concern was that the filters would clog prematurely with iron particulates in buildings with older galvanized steel piping causing reduced flow rates. In addition, the POU filters were set up and tested in the laboratory using municipal tap water spiked with known concentrations of lead and iron. Results of field sampling and laboratory testing indicated that the POU filter units successfully removed Pb from the influent water stream, even when iron particulates prematurely reduced the filter's flow capacity. For this lead variability study, iron testing in the Van Asselt School revealed that the building's water supply exhibited moderate levels of iron at the tap (<0.5 mg/L Fe) whereas the other schools that contained Type D plumbing configurations exhibited very low iron levels (<0.1 mg/L Fe). As such, the iron levels in the building's water supply did not appear to impact significantly the variability of lead levels at the tap based on the POU filtration units included in this study.

**Discussion of variability of lead.** The variability of lead levels in tap water depends on site-specific conditions including water quality characteristics and the nature and age of plumbing surfaces (Schock, 1990). In general, the quality of water delivered to Seattle Public Schools is relatively constant and field testing results indicate that LSH-11 was the only source of the Type A configuration that exhibited lead concentrations greater than 10 μg/L. The elevated lead levels and variability exhibited by LSH-11 in the first draw sample therefore could be attributed to corrosion and the release of lead from brass and other alloyed materials within approximately 6.5 ft (2 m) of plumbing from the bubbler head.

The most widely studied form of corrosion or deterioration of brass plumbing components and other alloyed fittings is known as "dezincification" (Schock, 1990; Grosvenor et al., 2005). When dezincification occurs, zinc is released from the brass or alloyed material and dissolved in the water. The dezincification process leaves behind a relatively greater proportion of lead and copper. Lead and copper can react in the presence of water by a corrosion process known as galvanic coupling. As more zinc is released from the alloyed material by dezincification, more galvanic corrosion occurs, thus allowing further release of lead into the water supply. This dezincification process therefore may have contributed to the elevated lead levels observed in samples collected from LSH-11 as part of this study.

Similar to results discussed previously for LSH-11 (Type A), the data for Type C sources indicate that lead likely was released to standing water located in end-use plumbing between the fitting and the POU filter system. As described previously, Type C configurations are characterized by plumbing with brass components downstream of the POU filter system. The elevated lead levels observed in the first draw samples from a Type C source (SCJ-03) therefore likely can be attributed to the dezincification process occurring in brass materials located between the fitting and the POU filter system.

Overall results of this variability study indicate that 12 samples out of a total of 768 samples or 1.6% of the total sample population exhibited Pb >10 μg/L. Nine of these 12 samples were collected from 2 sources (LSH-11 and SCJ-03) out of a total of 48 sources and exhibited lead levels ranging from 1.38 to 29.1 μg/L. If these 2 sources are considered aberrations and deleted from the sampling population, then the adjusted results of this variability study indicate that 3 samples out of a total of 736 samples or 0.4% of the adjusted population exhibited Pb >10 μg/L, with lead levels for these 3 samples ranging from 10.7 to 11.0 μg/L. These adjusted results show remarkable consistency in measuring lead levels less than 10 μg/L following remediation of drinking water sources in Seattle Public Schools.

As part of related studies for Seattle Public Schools (HDR, 2005), laboratory testing demonstrated that brass-containing fittings and components with mechanical parts (e.g., bubbler heads and shutoff valves) exhibited periodic spikes in Pb levels. These periodic spikes were attributed to the release of particulates associated with the release and turning of valves. In addition to the dezincification process discussed above, the variability in Pb levels observed in some drinking water sources at Seattle Public Schools, such as LSH-11 and SCJ-03, therefore could also be attributed to the release of particulates associated with the movement of mechanical parts during the testing period.

It should be noted that the new brass fittings and components were installed at selected drinking water sources during the past year. As part of related studies for Seattle Public Schools (HDR, 2005), laboratory testing demonstrated that new fittings and components containing brass materials can exhibit elevated Pb levels in testing immediately after installation, followed by a general decline in Pb levels with repeated tap water exposures attributed to passivation of exposed brass surfaces. This passivation period was demonstrated to extend from hours to weeks, depending on the specific materials and contact time. For this lead variability study, the new plumbing components likely were already passivated due to repeated exposure with tap water or as a result of pre-conditioning by Seattle Public Schools prior to their installation in the field. As such, the variability in lead concentrations observed in this study is more likely attributed to other factors such as the dezincification of brass materials or the release of particulates associated with movement of mechanical parts (e.g., valves) as described previously.

**Comparison of types of plumbing configurations.** Based on results of this special study, data summarized in Table 4 indicate that the type of plumbing configuration installed at a particular source can affect lead levels in drinking water in Seattle Public Schools. The highest lead levels were observed in the first draw samples collected from Type A and C plumbing configurations. Both of these types of configurations were characterized by fittings and components that contained standard brass materials (up to 8% Pb) in contact with standing water and located within the last 6.5 ft (2 m) of plumbing leading to the fitting. These samples also exhibited the greatest lead variability as indicated by the standard deviation and coefficient of variation values for Types A and C compared to these same statistical parameters for Types B and D.

**Accuracy and confidence levels of data from each type of configuration.** The *CV* determined for the first draw and flushed samples collected from each type of plumbing configuration (Table 4) were compared to the accuracy and confidence levels for lead in tap water samples as reported by Kirmeyer et al. (2004). The statistical relationships between *CV* and accuracy for an 80% confidence level are shown in Table 5. Knowing that 12 sources were tested for each type of plumbing configuration in Seattle Public Schools, a corresponding accuracy level was estimated from Table 5 for the *CV* determined from source testing in the schools. For example, first draw sampling data collected for Type A configurations in Seattle Public Schools yielded a calculated *CV* of 0.79 (Table 4). By scanning the sample sizes in the column for *CV* = 0.8 in Table 5, the corresponding accuracy level for 12 samples is 30%. For example, for the first draw samples collected from Type A plumbing configurations in Seattle

Public Schools, the variability testing program yielded a mean lead concentration of 3.91 μg/L, which can be reported with approximately a 30% level of accuracy and 80% confidence level. Similar analyses were conducted for other testing results in Seattle Public Schools.

Table 6 provides a summary of estimated levels of accuracy for first draw and flushed samples collected from each type of plumbing configuration in Seattle Public Schools. These estimates are based on an assumed confidence level of 80% and results generally indicate accuracy levels of approximately 15-45%. These accuracy estimates are somewhat greater than expected based on case studies reported by Kirmeyer et al. (2004). However, Kirmeyer et al. (2004, Figure 4.1) demonstrated that the variability of lead as measured by *CV* was greater at lower mean lead levels. Although not specifically examined as part of this study, the difference may be attributed to the magnitude of the lead concentrations used in the Kirmeyer et al. (2004) study compared to the lead levels reported in this variability study for Seattle Public Schools. Further, the 1-liter lead samples collected by water utilities and included in the case studies could also contribute to the different variability based on 250-mL samples collected at Seattle Public Schools. Thus, the variability of lead concentrations in tap water sinks based on 11 case studies could be expected to be greater than the variability of lead concentrations that were tested in Seattle Public Schools.

## CONCLUSIONS

A field testing program was developed and conducted in Seattle Public Schools to assess the variability of lead in drinking water. Four types of end-use plumbing configurations were identified as typical in Seattle Public Schools and 12 drinking water sources were selected to represent each type of plumbing configuration for further testing. Eight days of sampling (both first draw and flushed samples) were collected from each source after standing overnight, for a total of 768 samples collected during December 2005 through early February 2006. Results indicated that 12 samples or 1.6% of the total sample population exhibited Pb >10 μg/L, 4 samples or 0.5% exhibited Pb >20 μg/L, and none were greater than 30 μg/L.

The highest lead levels were observed in the first draw samples collected from Type A and Type C plumbing configurations. Both of these types of plumbing configurations were characterized by fittings and components that contained standard brass materials (up to 8% Pb) in contact with standing water. Samples collected from these two types of plumbing configurations also exhibited the greatest variability in lead concentration, which was attributed primarily to dezincification of lead-containing brass materials. Also, very low lead levels and variability were observed in samples with Type B plumbing configurations. Type B consisted of low-lead bubblers and new end-use plumbing components. Overall, the mean concentration of lead for all samples collected for this study was less than 5 μg/L, thus demonstrating the success of the water quality improvement program aimed at reducing lead levels in drinking water in Seattle Public Schools. The low-lead bubblers used in the Type B configuration are being installed at all remediated sources by Seattle Public Schools.

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## FOOTNOTE

1. Each POU filter system consisted of a 5µm pre-filter and a granular carbon media filter. Two different brands of granular carbon media filters were used during the variability study in Seattle Public Schools. For the purpose of this paper, these two brands are referred to as Z-brand and Y-brand cartridge filters.

**Table 1.** Results of Phase I Sampling at Seattle Public Schools.

| Sample | >10 μg/L | >20 μg/L | >30 μg/L | Total No. Samples |
|---|---|---|---|---|
| First draw | 1049 (33.1%) | 600 (19.0%) | 421 (13.3%) | 3,167 |
| Flushed (30-sec) | 221 (7.1%) | 91 (2.9%) | 55 (1.8%) | 3,136 |
| TOTAL | 1,270 (20.2%) | 691 (11.0%) | 476 (7.6%) | 6,303 |

**Table 2**. Sample pool size needed for various coefficients of variation (*CV*) and levels of accuracy and confidence for Pb levels at sink taps.

| **Accuracy Level (±%)** | **Number of Samples Needed for *CV* and Confidence Level** | | | |
|---|---|---|---|---|
| | **80% Confidence Level** | | **90% Confidence Level** | |
| | ***CV* = 0.2** | ***CV* = 0.4** | ***CV* = 0.2** | ***CV* = 0.4** |
| 5 | 26 | 105 | 43 | 173 |
| 10 | 7 | 26 | 11 | 43 |
| **15** | 3 | **12** | 5 | 19 |
| 20 | 2 | 7 | 3 | 11 |

* Based on Kirmeyer et al. (2004).

**Table 3**. Number of sources by type of plumbing configuration and dates of sampling occasions for variability testing in Seattle Public Schools.

| School | Iron Level[e] | No POU Filter | | POU Filter Systems | | 1st Sampling Week | 2nd Sampling Week |
|---|---|---|---|---|---|---|---|
| | | Type A | Type B | Type C | Type D | | |
| Graham Hill (GRH) | mod. | 3 | 1 | | | Dec 5-9 | Jan 9-13 |
| Van Asselt (VNA) | mod. | | | | 3[c] | Dec 5-9 | Jan 9-13 |
| Leschi (LSH) | v. low | 3 | 1 | | | Dec 5-9 | Jan 9-13 |
| Beacon Hill (BCN) | v. low | | 1 | 2[a] | | Dec 5-9 | Jan 9-13 |
| Rogers (RGS) | v. low | | 4 | 3[a] | 2[a] | Dec 12-16 | Jan 30–Feb 3 |
| Sacajawea (SCJ) | v. low | | | 4[a] | 2[a] | Dec 12-16 | Jan 30-Feb 3 |
| Broadview-Thomson (BDT) | v. low | | | 3[a] | 3[d] | Dec 12-16 | Jan 23-27 |
| Olympic View (OYV) | v. low | 3 | 4 | | | Dec 12-16 | Jan 23-27 |
| B.F. Day (DAY) | low | 3 | | | | Dec 12-16 | Jan 30–Feb 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kimball (KMB) | v. low | | 1 | | 2[b] | Jan 23-27 | Jan 30–Feb 3 |

[a] Z-brand cartridges were in place for 1st and 2nd sampling occasions.

[b] Y-brand cartridges in place for 1st and 2nd sampling occasions.

[c] One source contained Z-brand cartridge (VNA-03) and the other two sources (VNA-08 and VNA-14) contained Y-brand cartridges for both sampling occasions.

[d] Z-brand cartridges in place for 1st sampling occasion, and then replaced with Y-brand cartridges for 2nd sampling occasion.

[e] Iron levels defined by test sources in 2-min flushed samples: very low (v. low) exhibited Fe <0.1 mg/L; low exhibited Fe <0.3 mg/L; moderate (mod.) exhibited Fe <0.5 mg/L.

**Table 4.** Results of lead variability testing at selected drinking water sources in Seattle Public Schools.*

| Parameter | Type A | | Type B | | Type C | | Type D | |
|---|---|---|---|---|---|---|---|---|
| | **First Draw** | **30-sec Flush** | **First Draw** | **30-sec Flush** | **First Draw** | **30-sec Flush** | **First Draw** | **30-sec Flush** |
| Average (Mean) Pb (µg/L), $\overline{X}$ | 3.91 | 1.74 | 1.62 | 1.13 | 4.29 | 2.16 | 1.38 | 1.74 |
| Standard Deviation, $S_N$ | 3.08 | 1.21 | 0.80 | 0.41 | 5.27 | 2.02 | 0.71 | 1.66 |
| Coefficient of Variation, *CV* | 0.79 | 0.70 | 0.49 | 0.37 | 1.23 | 0.94 | 0.52 | 0.95 |
| Highest Pb (µg/L) | 19.2 | 8.27 | 5.28 | 3.09 | 29.1 | 10.7 | 4.14 | 11.0 |
| Number of Samples that Exceeded 10 µg/L (% of 96 total) | 5 (5.2%) | 0 (0%) | 0 (0%) | 0 (0%) | 5 (5.2%) | 1 (1.0%) | 0 (0%) | 1 (1.0%) |

* A total of 12 sources were tested for each type of plumbing configuration. A total of 96 first draw plus 96 flushed samples were collected from each source for this special study. All samples were 250mL in volume.

**Table 5**. Sample size for various coefficients of variation and accuracy levels – 80% confidence.*

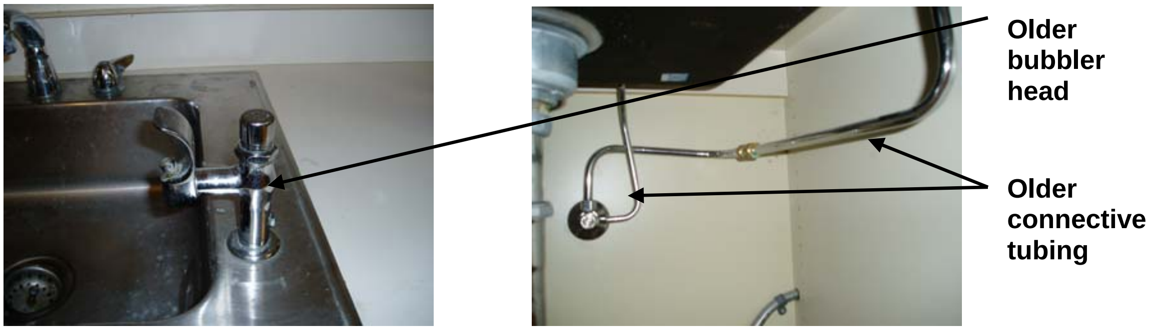
| Accuracy Level, % | Coefficient of Variation (standard deviation ÷ mean), *CV* | | | | | |
|---|---|---|---|---|---|---|
| | **0.4** | **0.5** | **0.7** | **0.8** | **1.0** | **1.5** |
| 5 | 105 | 164 | 322 | 420 | 657 | 1478 |
| 10 | 26 | 41 | 80 | 105 | 164 | 370 |
| 15 | **12** | 18 | 36 | 47 | 73 | 164 |
| 20 | 7 | **10** | 20 | 26 | 41 | 92 |
| 25 | 4 | 7 | **13** | 17 | 26 | 59 |
| 30 | 3 | 5 | 9 | **12** | 18 | 41 |
| 40 | 2 | 3 | 5 | 7 | **10** | 23 |
| 50 | 1 | 2 | 3 | 4 | 7 | 15 |

* Based on Kirmeyer et al. (2004), Table A.3.

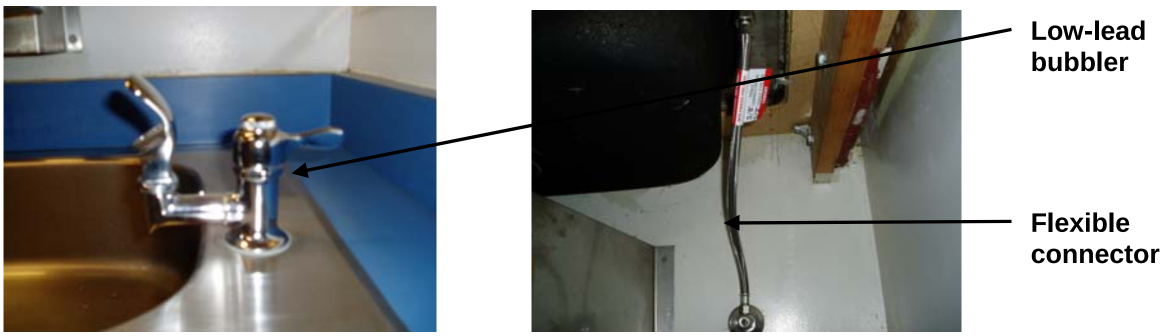
**Table 6.** Estimated level of accuracy of testing results in Seattle Public Schools with an assumed level of confidence of 80%.

| Parameter | Type A | | Type B | | Type C | | Type D | |
|---|---|---|---|---|---|---|---|---|
| | First Draw | 30-sec Flush | First Draw | 30-sec Flush | First Draw | 30-sec Flush | First Draw | 30-sec Flush |
| Average (Mean) Pb (µg/L), $\overline{X}$ | 3.91 | 1.74 | 1.62 | 1.13 | 4.29 | 2.16 | 1.38 | 1.74 |
| Standard Deviation, $S_N$ | 3.08 | 1.21 | 0.80 | 0.41 | 5.27 | 2.02 | 0.71 | 1.66 |
| Coefficient of Variation, *CV* | 0.79 | 0.70 | 0.49 | 0.37 | 1.23 | 0.94 | 0.52 | 0.95 |
| Accuracy level (±%) from Table 5 | 30 | 25 | 20 | 15 | 45 | 40 | 20 | 40 |

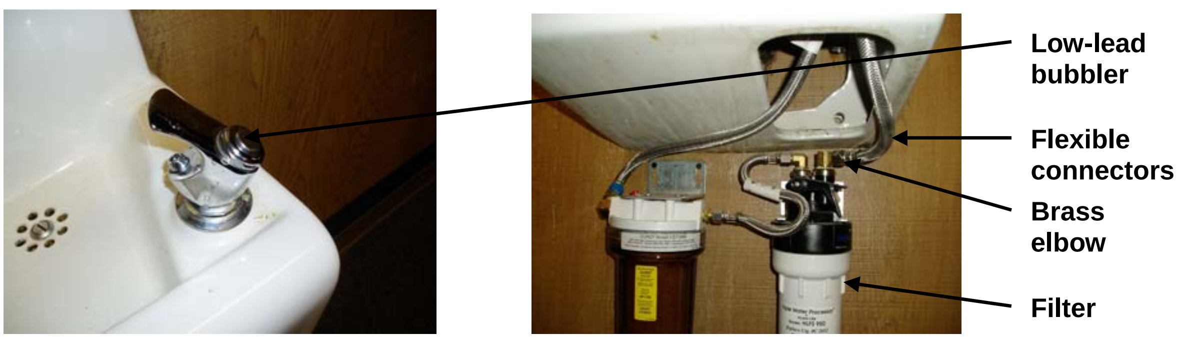
* A total of 12 sources were tested for each type of plumbing configuration. A total of 96 first draw plus 96 flushed samples were collected from each source for this special study.



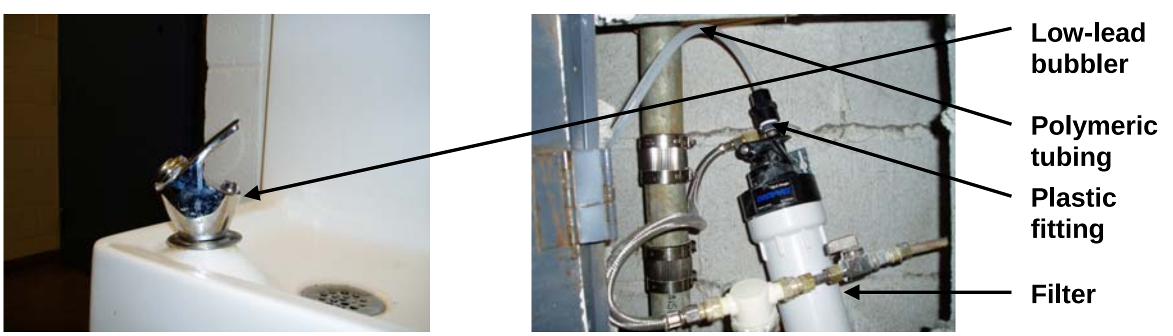

**Type A.** Typical older bubbler head, older connecting tubing, and older shut-off valve.




**Type B.** Typical new bubbler head, new flexible connector and new shut-off valve.

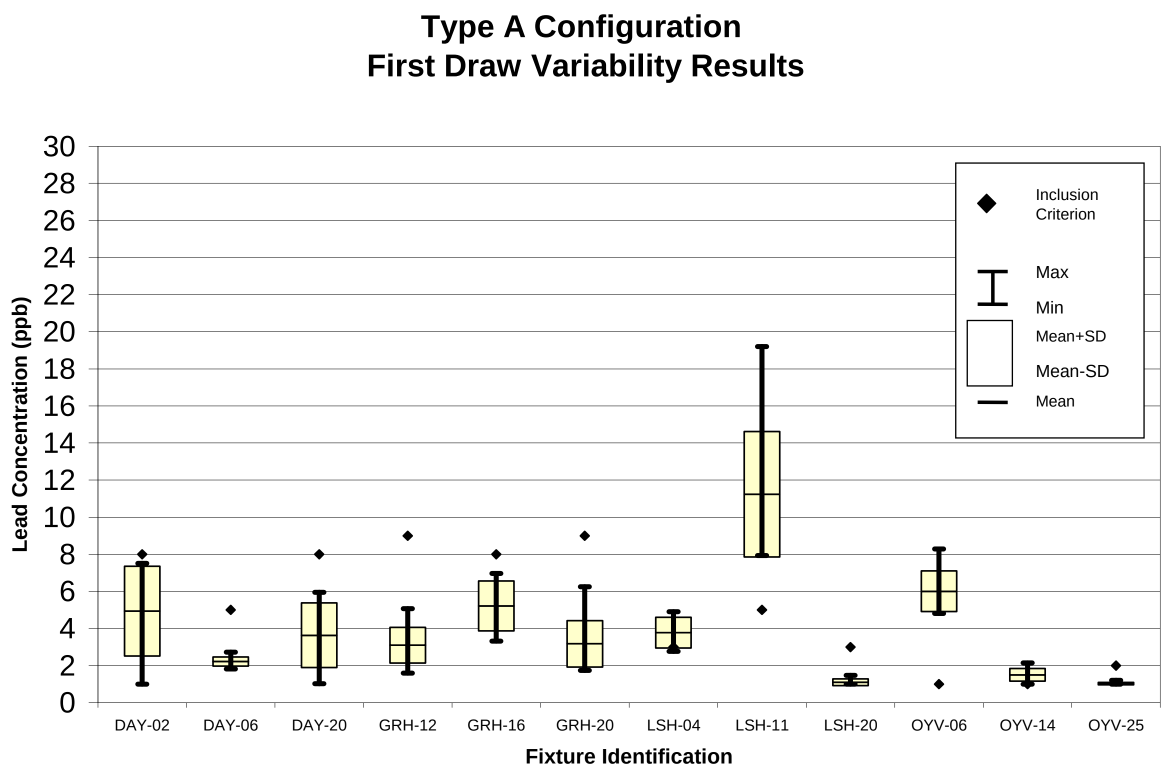



**Type C.** Typical new bubbler, new flexible connectors and shut-off valve, POU filter system, and brass elbow connectors.




**Type D.** Similar to Type C, but typically characterized by polymeric fittings and tubing from the filter effluent to the bubbler head.

**Figure 1**. Classification of end-use plumbing configurations in Seattle Public Schools.



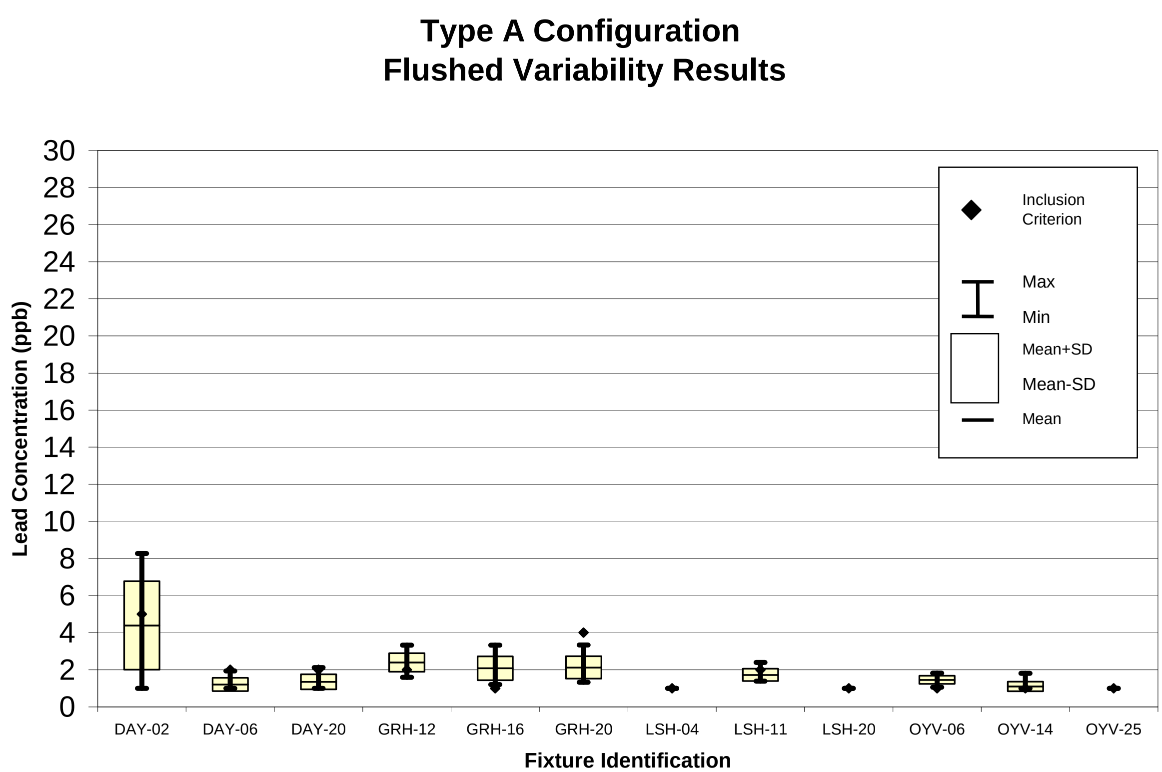
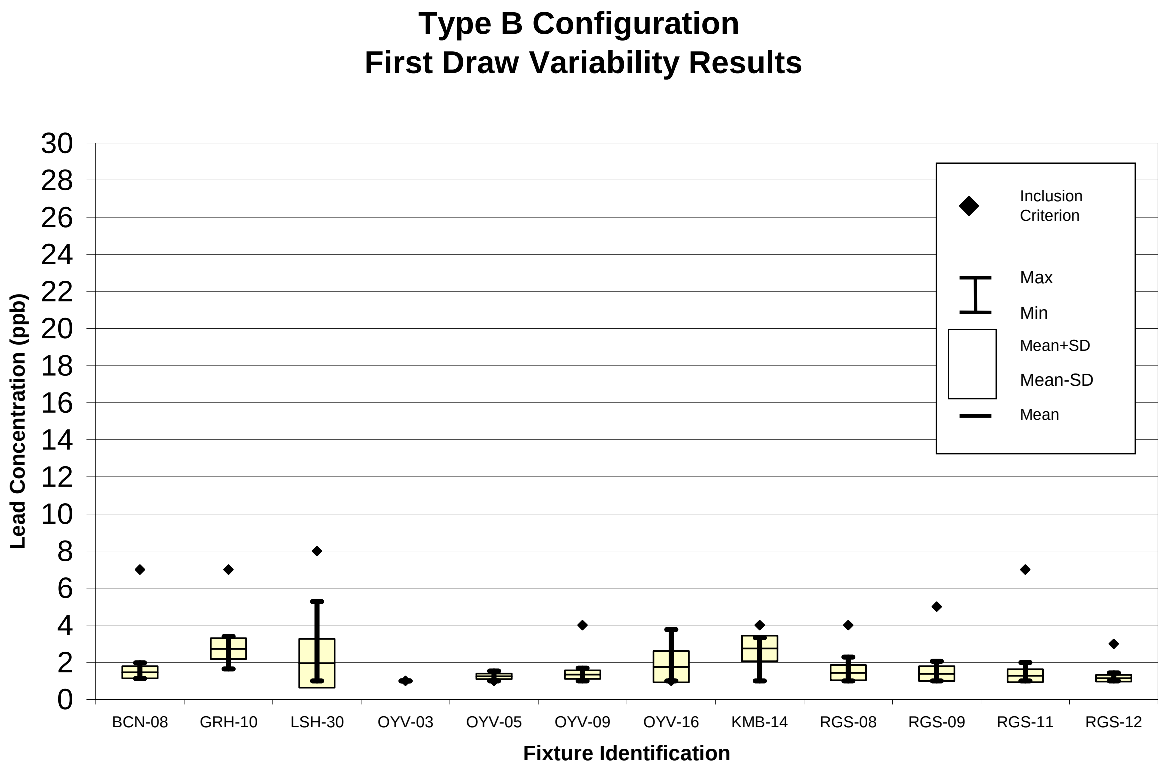




**Figure 2.** Lead sampling results of first draw samples (upper) and 30-second flushed samples (lower) for Type A plumbing configuration in Seattle Public Schools.



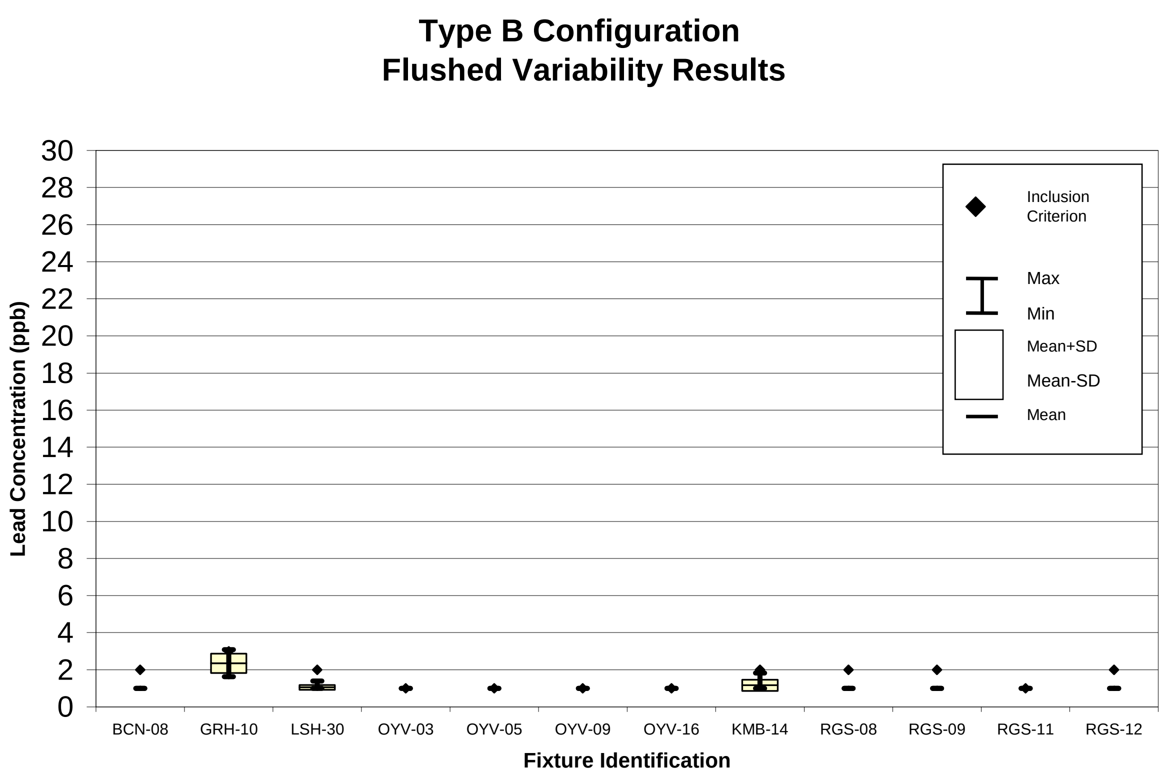
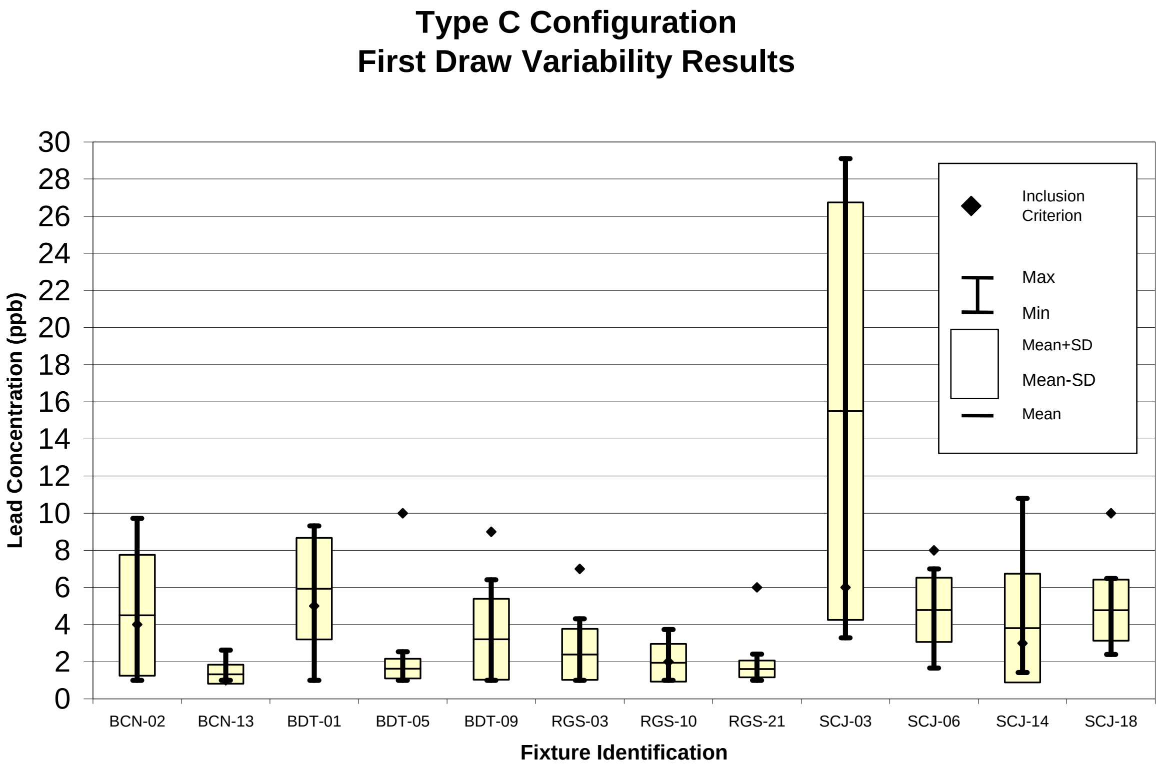




**Figure 3.** Lead sampling results of first draw samples (upper) and 30-second flushed samples (lower) for Type B plumbing configuration in Seattle Public Schools.



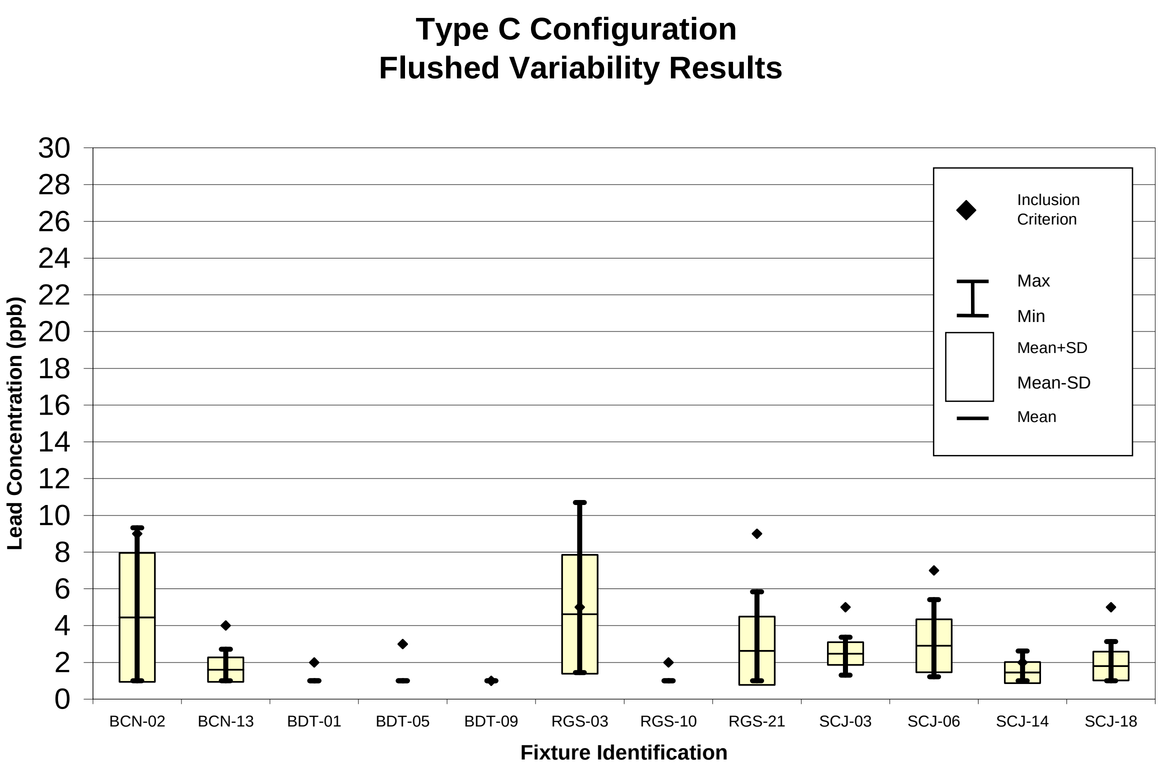
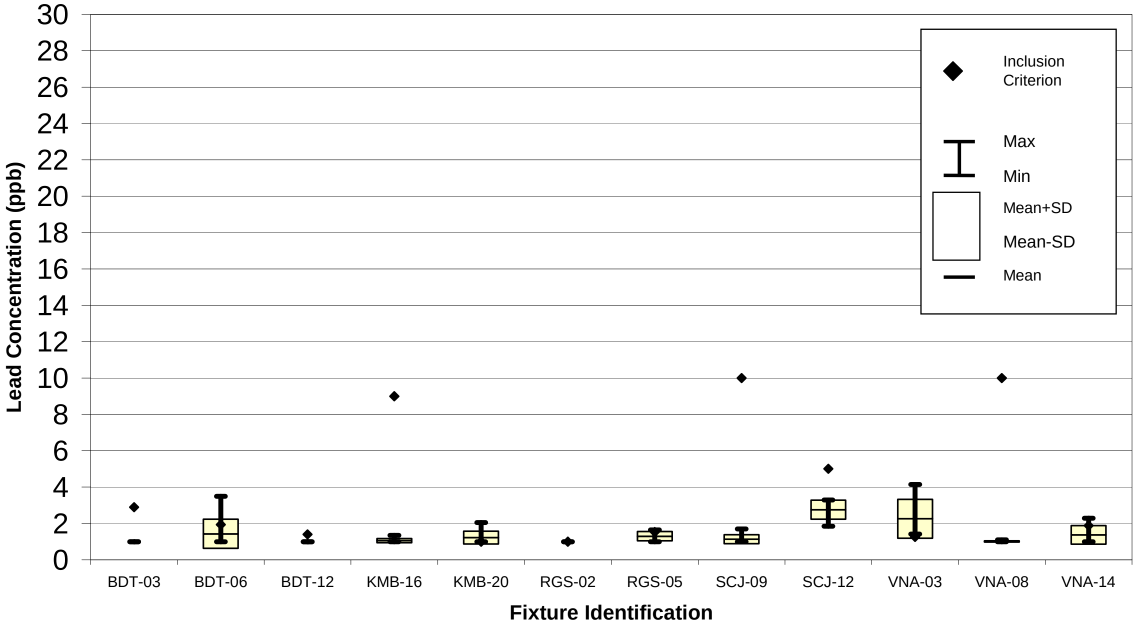




**Figure 4.** Lead sampling results of first draw samples (upper) and 30-second flushed samples (lower) for Type C plumbing configuration in Seattle Public Schools.

## Type D Configuration
## First Draw Variability Results




## Type D Configuration
## Flushed Variability Results

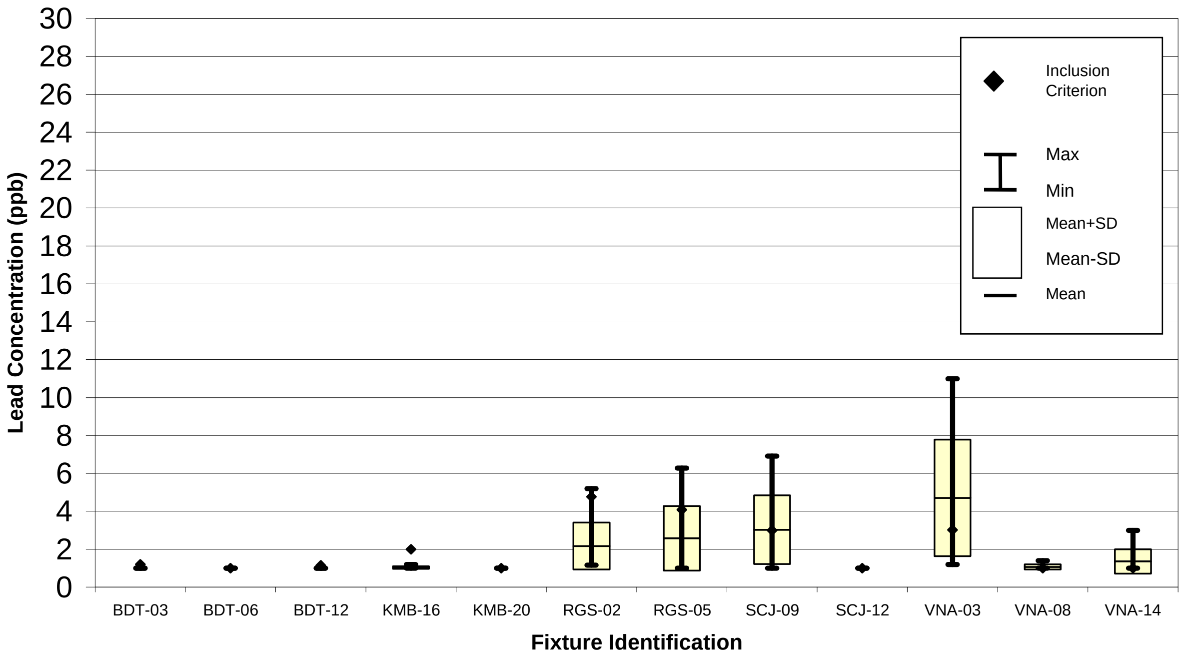



**Figure 5.** Lead sampling results of first draw samples (upper) and 30-second flushed samples (lower) for Type D plumbing configuration in Seattle Public Schools.