Assessing lead-contaminated drinking water in a large academic institution: a case study

Justin P. Miller-Schulze, Catherine Ishikawa and Jeffery A. Foran

ABSTRACT

Drinking water is an important source of lead exposure, and definitively characterizing the sources of lead in drinking water, particularly in large institutional settings, can be time-consuming and costly. This study examined lead concentrations in drinking water at a large university, focusing on variability in first-draw samples and variability with dispensed volume. Over 350 sources were sampled twice by independent groups, and while 78% of these samples were within 2.5 μg/L, almost 10% differed by >10 μg/L. In both sampling events, approximately 50% of sources had lead concentrations >1 μg/L, 6% were >15 μg/L, and 30% were between 1 and 15 μg/L. The highest lead concentration detected was 400 μg/L, with five sources >100 μg/L. Nine sources were sampled more intensively and six had first-draw sample ranges >5 μg/L. Lead concentration versus dispensed volume profiles indicated that while most sources had decreasing lead concentrations after the first draw, others had maximum lead concentrations at higher dispensed volumes. The variability observed suggests that assessments using only one or two samples per source may not identify all sources with elevated lead concentrations, and management strategies should account for this possibility.

Key words | drinking water quality, lead in drinking water

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INTRODUCTION

Exposure to low amounts of lead can lead to adverse health effects in both children and adults (Bellinger *et al.* 1987; Hara *et al.* 2015). For adults, successful reduction of lead in gasoline and paint has made food and drinking water the dominant routes of lead exposure (Health Canada 2017). For children, while ingestion of lead paint from older buildings continues to be a relevant source of exposure for some children, lead in drinking water has emerged as an important exposure pathway. As a result, preschool through secondary schools have been the subject of numerous studies of lead contamination of drinking water (Murphy 1993; Maas *et al.* 1994; Bryant 2004; Boyd *et al.* 2008a, 2008b; Massey & Steele 2012; Barn *et al.* 2013; Triantafyllidou *et al.* 2014; Deshommes *et al.* 2016; Doré *et al.* 2018; Sanborn & Carpenter 2018). These studies suggest that water lead levels (WLLs) vary considerably within schools and school districts, ranging from concentrations below the detection limit to >1,000 μg/L (Triantafyllidou *et al.* 2014; Deshommes *et al.* 2016).

The most common approach to assess WLL in schools and elsewhere is through 'first-draw' sampling where water is collected from a source after a long (6–8 h) period of stagnation (United States Environmental Protection Agency (U.S. EPA) 2006). The fraction of drinking water sources with first-draw WLL concentrations greater than a threshold value within a given school or district is variable. Sanborn & Carpenter (2018) reviewed lead monitoring efforts for 17 public school systems throughout the USA, and the percentage of first-draw samples >15 μg/L (the U.S. EPA Action Level for lead in drinking water) ranged

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from 0% to 12.3%, with a median of 5.8%. A large study of the drinking water sources in public schools in Canada found that 11% of first-draw samples in schools exceeded the Canadian lead drinking water threshold of 10 μg/L (Deshommes *et al.* 2016), while a study of 50 schools in New Jersey found that 50% of the sources exceeded 10 μg/L (Murphy 1993).

While variability in the fraction of first-draw samples exceeding a threshold can result from inconsistencies in sampling protocols, characteristics inherent to the drinking water system also contribute substantially to the variability. Differences in sampling protocols may include flushing the source prior to stagnation, and different volumes may be collected to represent first-draw samples. Characteristics in the water systems that affect WLL include water quality and treatment (Murphy 1993; Maas *et al.* 1994; Massey & Steele 2012; Clark *et al.* 2014; Doré *et al.* 2018), the types (including materials used to construct wetted components) and the ages of fountains and faucets (Maas *et al.* 1994; Boyd *et al.* 2008a; Deshommes *et al.* 2012; McIlwain *et al.* 2016; Doré *et al.* 2018), and the building age and plumbing configuration of individual structures (Massey & Steele 2012; McIlwain *et al.* 2016).

In addition to variability in WLL between and within institutions, WLL dispensed from a single source may vary depending on the use patterns and flow rate of the source, leading researchers to suggest that the ideal sampling protocol should include additional samples beyond the first draw (Murphy 1993; Clark *et al.* 2014; Doré *et al.* 2018). In many cases, WLLs decrease substantially after running the water from a source for 30 s to 10 min (Murphy 1993; Bryant 2004; Boyd *et al.* 2008b; Barn *et al.* 2013; Deshommes *et al.* 2016; Doré *et al.* 2018), and this periodic flushing of sources has been employed as a remediation strategy in a number of school systems in the USA (Sanborn & Carpenter 2018). However, the decrease in WLL with dispensed volume is not universal, as lead sources upstream from the source and particulate lead that may be dislodged as water runs through the system at high flow rates can lead to high levels of lead even after flushing is completed (Boyd *et al.* 2008a; McIlwain *et al.* 2016; Doré *et al.* 2018).

Recent studies have focused on WLL variability in larger institutional settings such as hospitals, penitentiaries, and universities (Deshommes *et al.* 2012; McIlwain *et al.* 2016; Doré *et al.* 2018). Universities warrant particular attention because of the large number of women of child-bearing age and the adverse effects, including deficits in memory recognition, language learning, and IQ (Geng *et al.* 2014; Dzwilewski & Schantz 2015), in young children exposed to lead *in utero*. Variability in WLL may be especially high in university settings, given the range of building age and size on many campuses, and use patterns that may be less predictable compared with elementary and secondary schools.

This study of lead-contaminated drinking water on a large public university campus in California adds to the body of research on variability in WLL in institutional settings and considers the implications of variability for decision-making in these settings. In this study, we examined WLL variability within individual drinking water sources as well as campus-wide variability. To characterize variability in individual fountains and faucets, we conducted repeated first-draw sampling and also investigated WLL as a function of the volume dispensed for a subset of fountains and faucets. In addition to presenting the results of this investigation, we discuss the difficulty in completely characterizing lead concentrations in drinking water from all water sources in a large institutional setting and the impact of this difficulty on decision-making and risk communication.

MATERIALS AND METHODS

The study was conducted at the California State University, Sacramento (CSUS) between December 2016 and August 2017. CSUS is a regional comprehensive university in north central California with approximately 30,000 students, 1,700 faculty, and 1,400 staff. CSUS sits on a 300-acre campus and uses 53 buildings for teaching and research, administration, and residential housing for students (CSUS 2019a). A map of the campus showing the distribution of these buildings can be found online (CSUS 2019b). The campus is also used throughout the year by a variety of groups from the community, including children, that are not directly affiliated with the University.

First-draw sampling of 452 campus drinking water sources, which included sinks and fountains, was conducted by CSUS faculty and students in January 2017, after a preliminary survey of 30 fountains in eight buildings, conducted March–June 2016, indicated low but detectable concentrations of lead in 15% of sampled drinking water sources. Eleven undergraduate and graduate students were recruited to conduct sampling consistent with EPA-3Ts (U.S. EPA 2006; U.S. EPA 2016) collection procedures for drinking water, without pre-stagnation flushing. Six hundred and eighty-three campus drinking water fountains and sinks were sampled by an external organization between April and June 2017, also following EPA-3Ts procedures (U.S. EPA 2006; U.S. EPA 2016), with pre-stagnation flushing on some fountains (fountains that had been shut down subsequent to the CSUS sampling). The sampling volume for these samples was 250 mL. No bias was evident in the 32 samples where pre-stagnation flushing was conducted (17 had higher lead concentrations for CSUS sampling and 15 had higher lead concentrations for the external organization), so they are included in results. The volume for these samples was 250 mL. Sample number differences between CSUS and the external organization resulted from access disparities during the two sampling periods. In total, nearly 700 fountains and faucets from 53 buildings spread over the 300-acre campus were sampled at least once during 2017. Three hundred and fifty-three fountains and faucets were sampled by both CSUS and the external organization. Data from both sampling efforts are included in this report.

Sampling to assess concentration variability within individual fountains and faucets was conducted by CSUS faculty and students during the summer of 2017. To determine whether and how lead concentrations changed as water was dispensed, we sampled nine drinking water fountains or faucets, each with lead concentrations between 5 and 15 μg/L as determined by both CSUS and the external organization. This range was chosen because sources with concentrations >15 μg/L had been shut down to protect public health and those with <5 μg/L could have concentration variability masked by measurement uncertainty, particularly when concentrations were <1 μg/L (i.e., within an order of magnitude of the detection limit).

We collected 100 mL samples at different dispensed volumes from each of seven fountains and two faucets using EPA-3Ts procedures (U.S. EPA 2006) without pre-stagnation flushing. Samplers collected a first draw of 100 mL, discarded the next 150 mL and then collected another 100 mL sample (which corresponded to 250 mL dispensed volume). This sequence was repeated, with the dispensed volume increasing to 4,000 mL at the completion of the study. The procedure was repeated (on different days) for three fountains selected for their diversity of concentration versus dispensed volume patterns from the first round of this type of sampling. The complete analysis resulted in the collection of 150 samples from 9 fountains and faucets over 6 weeks.

All samples were collected in 250 mL, acid-washed HDPE bottles and rinsed in nanopure water (deionized water with a minimum resistivity of 18.2 MΩ) prior to sampling. Trip blanks were composed of nanopure water that was dispensed into sampling bottles, transported to the sampling site and then submitted for analysis as a normal sample. Field blanks were produced by filling a sampling bottle with 100 mL of nanopure water immediately after collecting a drinking water sample at the sampling location. Trip blanks were collected at a frequency of once/sampling trip, and field blanks were collected at a frequency of once per sampling day per sampling group. All samples were acidified to 1% nitric acid by volume with trace metal grade nitric acid. Forty-eight blanks were collected during the internal sampling effort, lead concentrations in 82% of blanks were <0.11 μg/L and the highest concentration observed in any of the blank samples was 1.5 μg/L.

Samples collected by CSUS and the external organization were transported to and analyzed by the same third-party analytical laboratory, which was certified through the California Environmental Laboratory Accreditation Program, using EPA Method 200.8 (U.S. EPA 1994), to quantify lead by inductively coupled plasma mass spectrometry (ICP-MS). Laboratory quality control samples included a method blank and two matrix spikes for approximately every 15 field samples. Percent recovery and relative percent difference for the replicate matrix spikes were within 15%. For samples collected by the external organization, the method detection limit applied was 0.011 μg/L. For the samples collected by our group (CSUS), the applied detection limit was 0.11 μg/L. For data analysis, all values below the 0.11 μg/L detection limit were classified as <0.11 μg/L. Based on the lack of visible particulate matter, samples were not filtered prior to analysis by ICP-MS.

RESULTS

First-draw sampling

Approximately half of the drinking water sources sampled by CSUS and the external organization had lead concentrations below 1 μg/L (Table 1). Twenty-eight fountains or faucets (approximately 6%) sampled by CSUS, and 39 (approximately 6%) sampled by the external organization had lead concentrations above 15 μg/L, while 45% and 35% of CSUS and external organization samples had lead concentrations between 1 and 15 μg/L. The highest concentration of lead detected during the study was 400 μg/L, while five fountains or faucets sampled by each organization had lead concentrations above 100 μg/L.

We found mostly good agreement between percentages of samples in various ranges (e.g., >15 μg/L, between 1 and 5 μg/L, and <1 μg/L) measured by our group and the external consultant (Table 1). We also found mostly good agreement for paired first-draw samples collected by our group and the external consultant, with 277 out of the 353 co-sampled sources (78%) being within 2.5 μg/L of each other (Figure 1). However, almost 10% of sources sampled by the two groups differed by >10 μg/L. Eleven fountains or faucets had first-draw lead concentrations >15 μg/L in CSUS samples and <15 μg/L in samples collected by the external organization, while nine fountains or faucets had lead concentrations >15 μg/L in samples collected by the external organization and <15 μg/L in CSUS samples (Figure 2).

We did not see a relationship between lead concentrations at different sources in the same building, although one of the 53 buildings sampled did seem to have a disproportionate share of the high lead concentrations (Building B, Supplementary Material, Figures S1 and S2). We also did not observe a clear relationship between building age (Supplementary Material, Table S1) and lead concentrations, although all buildings where WLL >100 μg/L were observed were over 40 years old.

As a result of co-sampling and sampling for variability as a function of dispensed volume (discussed below), first-draw samples were collected from nine fountains and faucets at least three and as many as seven times during the study. First-draw concentrations of lead varied by >15 μg/L in

Table 1 | Summary of lead concentrations in sources sampled by CSUS and external entities at CSUS

	Number (%) of sources	
	CSUS	**External**
Total	452	683
>15 μg/L	28 (6)	39 (6)
5–15 μg/L	57 (13)	46 (7)
1–5 μg/L	142 (32)	188 (28)
0.11–1 μg/L	182 (40)	276 (40)
<0.11 μg/L	43 (10)	134 (20)

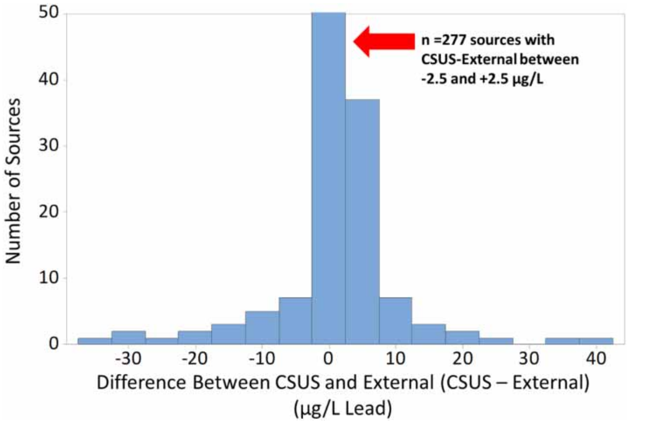


Figure 1 | Comparison of lead concentrations measured by external and CSUS sampling efforts, excluding seven fountains or faucets with lead concentrations >50 μg/L for one or both sampling efforts. The solid line is the 1:1 reference line, and dashed lines represent the EPA μg/L Action Level.

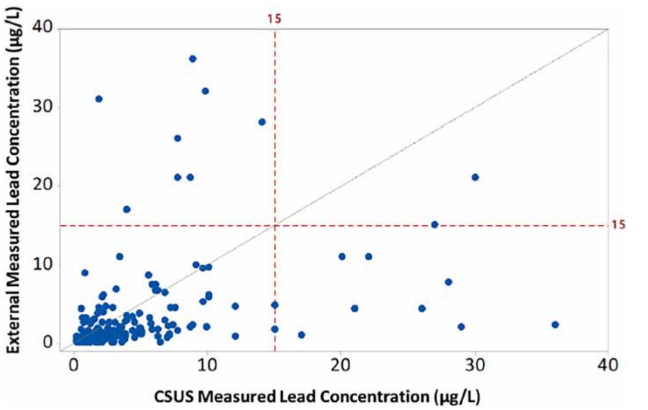


Figure 2 | Comparison of lead concentrations measured by external and CSUS sampling efforts, excluding seven fountains or faucets with lead concentrations >50 μg/L for one or both sampling efforts. The solid line is the 1:1 reference line, and dashed lines represent the EPA μg/L Action Level.

one source, by 5–15 μg/L in five sources and by 2.5–5 μg/L in three sources (Figure 3).

Variability with dispensed volume

Variability of lead concentrations with volume occurred in three distinct patterns (Figure 4). In six sources, elevated lead concentrations were detected in the first draw, and lower concentrations occurred as water was flushed through the system (Figure 4(a)). This pattern suggests that lead accumulated near the outlet over a period of time and was flushed relatively rapidly from the system. A second pattern (Figure 4(b)), represented by a low concentration at the first draw, an elevated concentration at a subsequent draw, and declining concentrations with continued flushing, suggests that the source of lead may be in local infrastructure, such as in the cooler of a water fountain. A third pattern (Figure 4(c)), where elevated lead concentrations are relatively uniform or where there is an elevated concentration at more than one time (e.g., first-draw and after significant flushing), suggests that lead may derive from plumbing components farther upstream of the drinking water source (e.g., building pipes) as well as components in the source fixture itself.

University response

Immediately after receiving results, university personnel temporarily removed from service all fountains with WLL

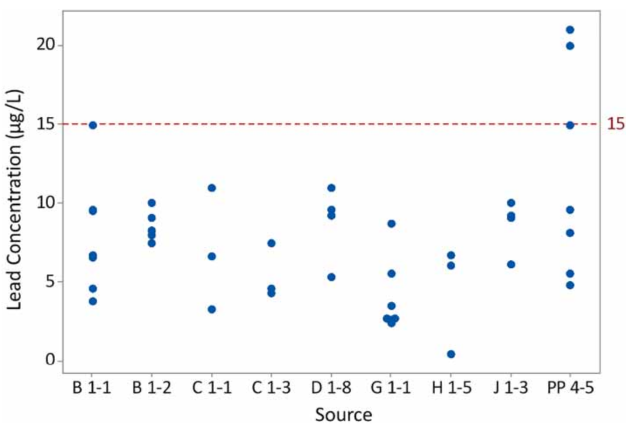
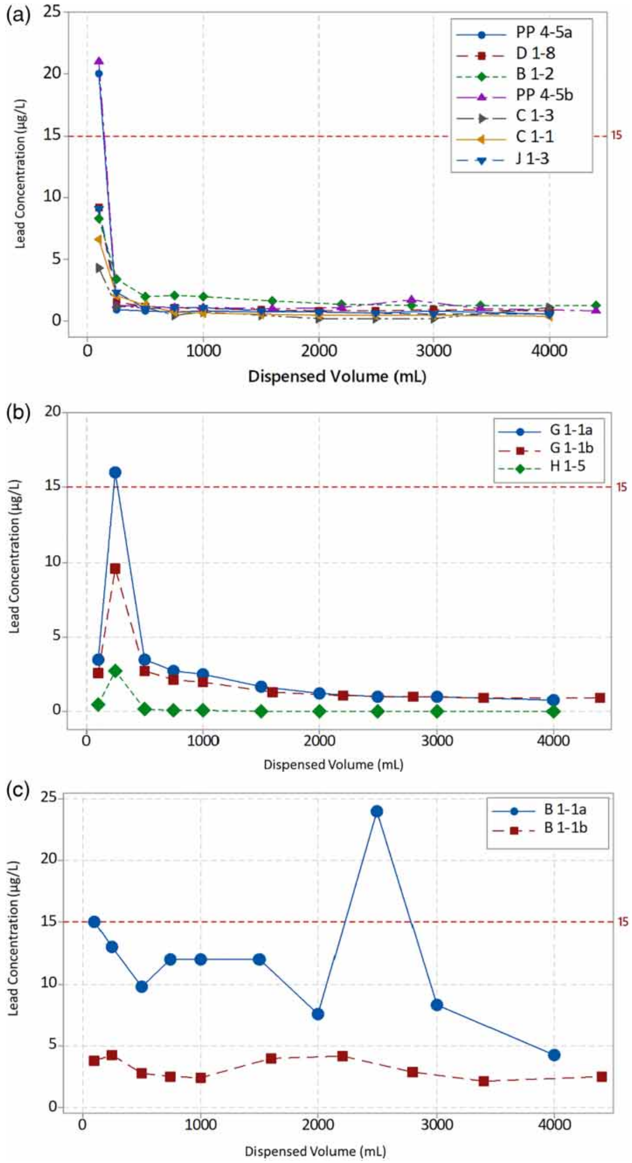


Figure 3 | Lead concentrations in first-draw samples for outlets with more than three first-draw samples conducted on them. The red dotted line represents the U.S. EPA Action Level (15 μg/L).



Figures 4 | (a–c) Variability in lead concentrations with dispensed volume.

>15 μg/L in either the CSUS or external sampling data sets. Subsequently, several fountains and faucets were permanently removed from service, and university staff remediated others by replacing all or parts of the fountains and faucets. Remediated fountains and faucets were returned to service. Fountains and faucets with first-draw WLL <15 μg/L were left in service. Some follow-up sampling has been conducted in remediated fountains and faucets, and additional sampling is planned over the next 4 years for fountains and faucets with WLL <15 μg/L.

Communication with the campus community began 12 days after initial first-draw sampling. A general notification was provided to students, faculty and staff about lead contamination on the CSUS campus, explaining that fountains and faucets with concentrations >15 μg/L had been removed from service until they could be remediated. After remediation, University officials notified students, staff and faculty that water from fountains and faucets with lead concentrations <15 μg/L was safe to drink. Quick response (QR) codes were placed on fountains and faucets, providing information about the most recent concentration of lead detected in water from each source. QR codes also directed users to a web site that provides access to a database with the most recent lead concentrations for each drinking water source, although very little information on health effects was made available via the QR codes. University personnel installed water fountains with lead-certified filtration (NSF/ANSI 53) systems on the first floor of every building. We are not aware of any follow-up sampling to check that these bottle fillers are effective, but similar models tested during our sampling had low WLL. Unfortunately, little to no direction to these fountains was provided, and unfiltered fountains and faucets remain in service.

DISCUSSION

Our assessment of drinking water on the CSUS campus represents, to our knowledge, the largest study of lead contamination of drinking water in a university setting. The results of this work show that a low but not insignificant percentage (ca. 6%) of first-draw samples had WLLs greater than the 15 μg/L EPA Action Level. This proportion is similar to that found in studies of other schools. The median percentage of sources with WLL >15 μg/L was 5.8% for the school districts reviewed in Sanborn & Carpenter (2018), and in an analysis of over 12,000 water sources in schools and private workplaces, Maas *et al.* (1994) reported that 17% were >15 μg/L. We also found that very high and very low lead concentrations occurred in the same building, consistent with other studies (Deshommes *et al.* 2016; McIlwain *et al.* 2016). However, we did not find an association between fountain brand and high lead concentrations, in contrast to other work (McIlwain *et al.* 2016), although some fountain brands assessed by McIlwain have, in fact, been banned in the USA.

Few studies have repeated first-draw sampling on the same fountains or faucets, and none have duplicated first-draw sampling at the scale conducted in our study. The fact that a similar proportion of sources had WLL exceeding the EPA Action Level of 15 μg/L when sampled by our group and the external consultant, even with some differences in the sampling methods (100 versus 250 mL sampling volume and pre-stagnation flushing), is reassuring from an assessment perspective. However, a small number (11 and 9, respectively) of fountains had lead concentrations >15 μg/L in the CSUS sampling but <15 μg/L in the external sampling or vice versa. Thus, a single sampling event would not have identified all the sources with first-draw samples greater than the EPA Action Level.

We also observed variability in first-draw WLL from the same source sampled on multiple days (Figure 3). This type of variability has been observed in other studies (Boyd *et al.* 2008b; McIlwain *et al.* 2016). For example, Boyd *et al.* (2008b) collected first-draw samples from 12 fountains over 8 days and observed variability similar to our observations (one source ranged from 8 to 19 μg/L, 8 out of 12 sources had ranges of >2 μg/L). McIlwain *et al.* (2016) collected volume profiles for a single fountain on nine different days and first-draw WLL for this fountain ranged from approximately 6 to 22 μg/L. This variability presents a challenge for the management of lead exposure from drinking water.

The change in WLL as a function of volume that we observed on the CSUS campus for the sources described in Figure 4(a) is similar to that described in other studies that did volume profiles (Boyd *et al.* 2008b; McIlwain *et al.* 2016). Behavior of this type would support a flushing protocol as a method to reduce lead exposure from these sources. However, fountains with delayed decreases (Figure 4(b)) or no consistent decrease (Figure 4(c)) are more analogous to the fountains of problematic construction assessed by McIlwain *et al.* (2016), where a decrease in lead concentration with volume dispensed did not occur.

Boyd *et al.* (2008b) also observed a number of fountains in which subsequent draws had a higher WLL than first draws. Exposure from these sources might not (Figure 4(b)) or would not (Figure 4(c)) be reduced by daily flushing protocols. Our results of the sources sampled intensively to produce Figure 4(a)–4(c) are consistent with research on flushing as a method of reducing lead exposure. Aggregate measures of WLL (i.e., medians, means, 90th percentiles or percentages above threshold values) are consistently reduced, but the fact that these aggregate measures remain above the detection limit after flushing indicates that not all drinking water sources neatly follow the pattern of Figure 4(a) (Murphy 1993; Bryant 2004; Boyd *et al.* 2008b; Barn *et al.* 2013; Doré *et al.* 2018). The challenge is determining, without an extensive characterization effort, which sources do not follow the pattern.

Strategies for management of lead-contaminated drinking water in institutional settings

Assessing lead contamination of drinking water by first-draw sampling alone may miss 'worst-case scenarios' for some fountains or faucets (i.e., sources where the maximum lead concentration occurs after the first 100–250 mL dispensed), and public health may be at risk. To be certain that outlets with elevated lead concentrations are not available to users, detailed analysis of each fountain and faucet would be necessary. For example, Doré *et al.* (2018) recommend a 'two-tiered' sampling approach in which first-draw sampling is combined with follow-up sampling for sources with WLL >10 μg/L. Follow-up sampling would include both a first-draw sample and a sample after a 1-minute flush. If employed at CSUS, this would have resulted in a 'follow-up' sampling of approximately 8% of the drinking water sources on campus, i.e., 58 sources. This approach might have 'missed' (not identified for follow-up sampling) one of the two fountains identified in Figure 4(b), which had a WLL of >10 μg/L in the second 100 mL sample collected (representing 350 mL dispensed) but not in the first-draw sample. Tiered sampling approaches that assume a volume versus concentration relationship like that of Figure 4(a) will fail to address outlets that behave differently. Therefore, approaches to remediation and management of lead must be robust enough to account for possible missed sources, so that lead exposure will be reduced to very low levels or, ideally, eliminated as quickly as possible.

As noted above, the flushing strategy employed by primary and secondary schools in the USA and Canada (Aguilera 2018; Sanborn & Carpenter 2018) may not be effective when lead contamination originates at a location substantially upstream of the outlet. We also question the viability of this approach on the CSUS campus, with its 53 buildings and over 300 acres, due to the logistics and costs involved. In addition, the literature suggests that the benefits of flushing may not extend throughout the entire day. Doré *et al.* (2018) reported that after a 30-minute stagnation period following flushing, WLL were back to 45% of the first-draw lead concentrations. Murphy (1993) re-sampled flushed fountains on an elementary school campus and found that median WLL returned to 7 μg/L, 70% of the first-draw median of 10 μg/L. Thus, large institutions may want to consider other alternatives in addition to or in place of flushing as a method of reducing lead exposure from drinking water.

On the CSUS campus, new fountains and bottle fillers with filters certified to remove lead are being installed in buildings. Installation of this technology is occurring concurrent with the replacement of fountains, or components of fountains and faucets, where elevated lead concentrations (>15 μg/L) have been detected. This approach has not been assessed for efficacy at CSUS, but a study of lead concentrations in drinking water before and after the installation of point-of-use (POU) filtration devices at a federal penitentiary complex (Deshommes *et al.* 2012) showed that POU filtration devices significantly decreased dissolved and particulate lead concentrations, even where the particulate fraction of lead was double the soluble lead concentration. Therefore, providing clearly identified sources of drinking water with the maximum available removal technology is an ideal management strategy in this and perhaps many, large institutional settings.

CONCLUSIONS

In the first large-scale study of WLL on a university campus, lead was found to be a widespread contaminant of drinking water at a large public university in California, with WLL ranging from non-detect (<0.11 μg/L) to > 400 μg/L in campus fountains and faucets. These data, in combination with the growing body of work on lead in institutional settings, demonstrates that variability in WLL, whether between first draws or as a function of dispensed volume, presents challenges for both assessment and management of lead in drinking water at large institutions. Sources of drinking water with variable first-draw concentrations or peaks in WLL at larger dispensed volumes may appear to meet acceptable standards during assessments based on a single first draw, but may dispense water with WLL greater than a given threshold value. Similarly, daily flushing of fountains may fail to lower WLL below target levels depending on the kinetics of lead leaching in that specific source.

Our paired sampling on a large number of sources indicated that sources with low first-draw WLL tended to be low during both sampling events. However, further studies in which volume profiles were developed for sources with low first-draw WLL should be conducted to determine whether WLL may increase with larger dispensed volumes from these sources as well.

In light of the challenges variability in WLL of drinking water sources present, the option of providing clearly identified lead-free drinking water sources (Doré *et al.* 2018) seems to be a reasonable management strategy in a university setting. On the CSUS campus, at least one bottle filler with filters certified to remove lead has been installed in each building. Clear communication to users about the relative safety of all drinking water sources available is an important component of this management approach, so that those at greatest risk may make informed choices about which sources to use.

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