Water Research 99 (2016) 46–55

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Evaluation of exposure to lead from drinking water in large buildings

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A R T I C L E I N F O

Article history:
Received 17 December 2015
Received in revised form
30 March 2016
Accepted 19 April 2016
Available online 22 April 2016

Keywords:
Schools
Bloods lead levels (BLLs)
Tap water
Risk of exposure
Children

A B S T R A C T

Lead results from 78,971 water samples collected in four Canadian provinces from elementary schools, daycares, and other large buildings using regulatory and investigative sampling protocols were analyzed to provide lead concentration distributions. Maximum concentrations reached 13,200 and 3890 μg/L following long and short stagnation periods respectively. High lead levels were persistent in some large buildings, reflected by high median values considering all taps, or specific to a few taps in the building. Simulations using the Integrated Uptake Biokinetic (IEUBK) model and lead concentrations after 30 min of stagnation in the dataset showed that, for most buildings, exposure to lead at the tap does not increase children's blood lead levels (BLLs). However, buildings or taps with extreme concentrations represent a significant health risk to young children attending school or daycare, as the estimated BLL far exceeded the 5 μg/dL threshold. Ingestion of water from specific taps could lead to acute exposure. Finally, for a few taps, the total daily lead intake reached the former World Health Organization (WHO) tolerable level for adults, suggesting potential health risks.

1. Introduction

Extreme lead concentrations have been reported in large buildings. These elevated concentrations result from the combination of three factors: water quality which favours lead corrosion, long stagnation times, and the presence of lead-bearing components. Leaded solders, brass fittings, fountains, and taps are typically the sources of lead in tap water in large buildings (Cartier et al., 2012; McIlwain et al., 2015). These can contribute to significantly higher lead levels when compared to those observed in households with lead service lines. Up to 1600 μg/L of lead was measured in Seattle schools (Boyd et al., 2008), up to 1987 μg/L in Washington DC schools (Triantafyllidou et al., 2009), and up to 1000 μg/L at taps used for consumption in Canadian penitentiary complexes (Deshommes et al., 2012). This situation is not restricted to old buildings. Elfland et al. (2010) reported lead concentrations of 350 μg/L at fountains in a new building and identified brass fittings as the main source.

Lead is neurotoxic for young children and fetuses and is associated with intellectual deficit even at low blood lead levels (BLLs) previously considered to be safe (Canfield et al., 2003; CDC, 2012). Considering these adverse effects and the lack of a safe threshold, specific guidelines have been published for schools. Since 1994, the USEPA has formulated guidance to support sampling and remediation actions to lower lead concentrations in schools (USEPA, 2006). Recently, new regulations were introduced to reduce the maximum acceptable total lead content in brass fixtures from 8% to 0.25%. In Ontario (Canada), regulatory monitoring was implemented in 2007, as well as flushing in schools and daycares (Government of Ontario, 2007). In collaboration with public health services, New-Brunswick school boards have completed comprehensive lead sampling at every tap of every school, along with remediation actions (The Canadian Press, 2012).

The contribution of lead in tap water in households to the BLLs of children has been demonstrated in Washington DC (US),

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http://dx.doi.org/10.1016/j.watres.2016.04.050
0043-1354/

Montreal (Canada), Glasgow (UK), France, and recently in Flint, Michigan (Brown et al., 2011; Deshommes et al., 2013; Hanna-Attisha et al., 2016; Levallois et al., 2013; Oulhote et al., 2013; Watt et al., 2000). Information is however scarce regarding the exposure of young children to lead in the tap water of schools and daycares. When compared to residential households with lead service lines, lead release in non-residential large buildings is mostly in the particulate form and flushing is not always effective for reduction due to the high volume of piping and low water usage (Deshommes et al., 2012; Elfland et al., 2010). Lead concentrations can vary significantly in the same building, depending on the components of the tap sampled and upstream fixtures. Corrosive water and intermittent use also contribute to increased lead levels (Barn et al., 2014; Elfland et al., 2010; McIlwain et al., 2015). By applying the United States Environmental Protection Agency (USEPA) Integrated Exposure Uptake Biokinetic model (IEUBK), Sathyanarayana et al. (2006) showed that exposure to lead in tap water in Seattle public schools resulted overall in a geometric mean BLLs below the 5 μg/dL threshold set by the CDC (CDC, 2012). Deshommes and Prévost (2012) estimated that large buildings with high particulate lead concentrations can contribute to BLL exceedances in young children. Moreover, when considering pre-flushed lead concentration results from 5 schools in British Columbia, Canada, Barn et al. (2014) estimated that the total lead intake of children increased 2-fold when compared to Health Canada estimates. Finally, limited benefits of lead remediation efforts (flushing, pipes/fountains/bubbler heads replacement) on the exposure of children in schools were reported for two systems served by distinct water qualities, both of which met the federal lead regulation of 10 μg/L (90th percentile) at household taps (Triantafyllidou et al., 2014).

It is estimated that for children between 7 and 10 years old, lead absorption rates decrease from about 50% to 10%, and then remain stable (Mushak, 1991). Most studies focusing on children's exposure consider high absorption rates and low body weights when compared to adults. Exposure of adults has been limited to specific cases of occupational exposure. Nonetheless, adverse impacts of lead for adults and at BLLs below 10 μg/dL have been documented, notably with respect to cardiovascular effects and renal effects (Ekong et al., 2006; Menke et al., 2006). As a consequence, the WHO provisional tolerable weekly intake (PTWI) of 25 μg Pb/kg body weight/week (μg Pb/kg bw/week) was put off (WHO, 2011). Moreover, the USEPA developed the All Ages Lead Biokinetic Model (AALM) and is currently updating its 2005 version (US EPA, 2005).

In this study, results were gathered from regulatory and investigative lead sampling campaigns in large buildings in Canada, including schools, daycares, and public large buildings. These lead concentrations were used to estimate the exposure of children and adults to lead resulting from the consumption of tap water from these locations.

2. Materials and methods

2.1. Lead sampling data

Data were gathered from 8530 large buildings (defined as non-residential buildings) in four Canadian provinces, including elementary schools, secondary and high schools, universities, hospitals, and penitentiaries. Most of the data originates from sampling campaigns conducted by large buildings' staff for regulatory purposes (n = 70,709 samples) or remediation purposes (n = 7332 samples) in three provinces using Health Canada's guideline for non-residential buildings (2009). Data from additional investigative sampling in three provinces to determine the source of lead and the impact of sampling protocols (n = 930 samples) were also included (Cartier et al., 2012; Deshommes et al., 2012; Doré et al., 2013; McIlwain et al., 2015). All samples were taken from cold water taps used for consumption, including fountains, classroom taps, kitchen or cafeteria taps, and bathroom taps.

Depending on the data subset, first flush results alone or combined with other sampling protocols were available for all taps sampled in the buildings (see Supporting Information SI). First flush sampling consisted of collecting the initial volume of tap water after overnight stagnation, consisting of at least 6 h but no more than 24 h (6hS-1), except for buildings where stagnation could not be controlled due to usage patterns (hospitals, universities, penitentiaries) or for which taps were not systematically pre-flushed the day before sampling (penitentiaries). The volume collected varied between 125 mL, 250 mL, and 1 L depending on the sampling protocol used, although 1 L samples represented the majority of the dataset (85%). Second flush sampling (6hS-2) consisted of 1750 mL water samples collected immediately following the first sampling. This type of sampling was limited to 57 taps in the dataset. Other samples included those collected after flushing the tap for 30 sec (30sF, 125–250 mL) and 5 min (5minF, 250 mL) following the collection of first draw samples (6hS-1, or 6hS-1 and 6hS-2). Finally, 30 min stagnation samples of 250 mL or 1 L in the dataset were collected after flushing the tap for 5 min followed by 30 min of stagnation, with 1 L samples representing >95% of the dataset (30minS).

All samples were collected in polypropylene bottles and acidified to pH < 2 with nitric acid for at least 16 h. The percentage of acid addition by volume varied between 0.15% and 2% depending on the dataset. Total lead concentrations were analyzed according to EPA 200.8 method by accredited laboratories and academic research laboratories, using inductively coupled plasma mass spectrometry (ICP-MS). Detection limits varied between 0.02 and 0.5 μg/L depending on the laboratory. For one dataset containing 51% of all 30sF data and 6% of all 6hS-1 data, only values above the quantification limit (1.0 μg/L) were available. Values below the detection or quantification limit were considered equal to 0.01 μg/L.

Data were segregated according to the age of the main users in the large buildings. To estimate young children's exposure, daycares and elementary schools were grouped into one dataset and categorized as '0–7 yrs dataset' (children). Similarly, to estimate older children and adult exposure data from other large buildings were grouped into a second dataset classified as '7–99 yrs dataset'. The distribution of the data as well as the types of samples collected for each dataset are shown in Table 1.

2.2. Estimation of children's exposure in elementary schools

The USEPA IEUBK model (version win1_1 Build11) was used to analyze the impact of lead on young children's (0–7 yrs) BLLs. Background exposure from sources other than tap water in the model (soil, dust, air, and food) was selected according to recent Canadian values (Table 2; see Table S1 for additional details). These parameters were validated by Deshommes et al. (2013) as representing children's background exposure to lead in urban areas, as the modelled BLLs were very close to the BLLs measured in 306 children (0–5 yrs) living in households without a lead service line in an epidemiological study (Levallois et al., 2013). The batchrun mode of IEUBK was used as described by Deshommes et al. (2013) to include varying exposure of children to water lead levels before and after starting school at approximately 5 years of age. From 0 to 5 years old, it was assumed that children drank 100% tap water containing 2 μg/L lead, which is representative of concentrations in a household with no lead service line according to previous sampling studies (Deshommes et al., 2013). For 5–7 years age range (age limit for IEUBK simulations), it was considered that children