Investigating elevated copper and lead levels in school drinking water

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Abstract: Copper and lead continue to be detected at levels above drinking water guidelines in Canadian schools. Although water is typically not an important source of these metals, intermittent use and corrosive water can cause copper and lead to leach from plumbing. Exposure to elevated copper levels is linked to acute gastrointestinal effects in the short term and possible liver effects in the long term, whereas even low level lead exposures are associated with neurodevelopmental effects. Because school water is not regularly monitored for corrosion metals, elevated concentrations are often brought to the attention of public health officials through unexpected circumstances. Here, the death of salmon eggs in a classroom aquarium triggered an investigation that found elevated levels of copper and lead in the school's drinking water. The investigation was then expanded to the school district. Copper and lead levels varied considerably across schools as well as in outlets located in the same school. The effectiveness of flushing, which was implemented as a mitigation strategy, was also found to differ by school building and outlet. Actions described in this case report may be informative for health authorities across Canada.

Key words: lead, copper, drinking water, school, assessment, flushing.

Introduction

Copper and lead are associated with adverse health effects depending on both the level and duration of exposure. Effects can range from gastrointestinal (copper) to neurological (lead). These metals mainly enter drinking water systems through corrosion of copper- and lead-containing plumbing including pipes and fixtures. Intermittent water use that occurs throughout the school day can contribute to elevated concentrations of these metals. Although elevated lead concentrations continue to be found in school water across Canada (The Canadian Press 2012), drinking water quality is not routinely monitored in schools. Ontario is the only province that requires regular monitoring of metals in school drinking water (Ontario Ministry of the Environment 2010). This paper describes the series of actions that led to the identification, sampling, assessment, communication, and mitigation of copper and lead in school drinking water in a BC community (Figure 1).

Identification

The local school board first became aware of issues with water quality at the school (S1) after testing was conducted by a Department of Fisheries and Oceans (DFO) employee. The DFO employee was contacted by a school staff member who was concerned that salmon eggs displayed in a classroom aquarium were not surviving. The DFO employee tested a sample of water from the classroom sink for copper, a known aquatic toxicant and found a concentration of 8.36 mg/L. As this level was eight times higher than the copper drinking water guideline (1 mg/L), the DFO employee shared the results with the local health authority (HA) and the school's principal. In consultation with the Chief Medical Health Officer, the HA advised the school board to flush the plumbing at S1 for a minimum of two minutes each morning, beginning the next day as an interim measure, pending further investigation.

Sampling and interim mitigation

Additional sampling was conducted at S1 to assess the extent of both copper and lead contamination. Potential leaching of lead from household plumbing had previously been raised as an issue by the HA to the Public Works Department due to the aggressiveness of the community's water supply, including a low pH level. The following day, pre-flush and two-minute post-flush samples were collected from a classroom sink and a drinking water fountain at the opposite end of the school.

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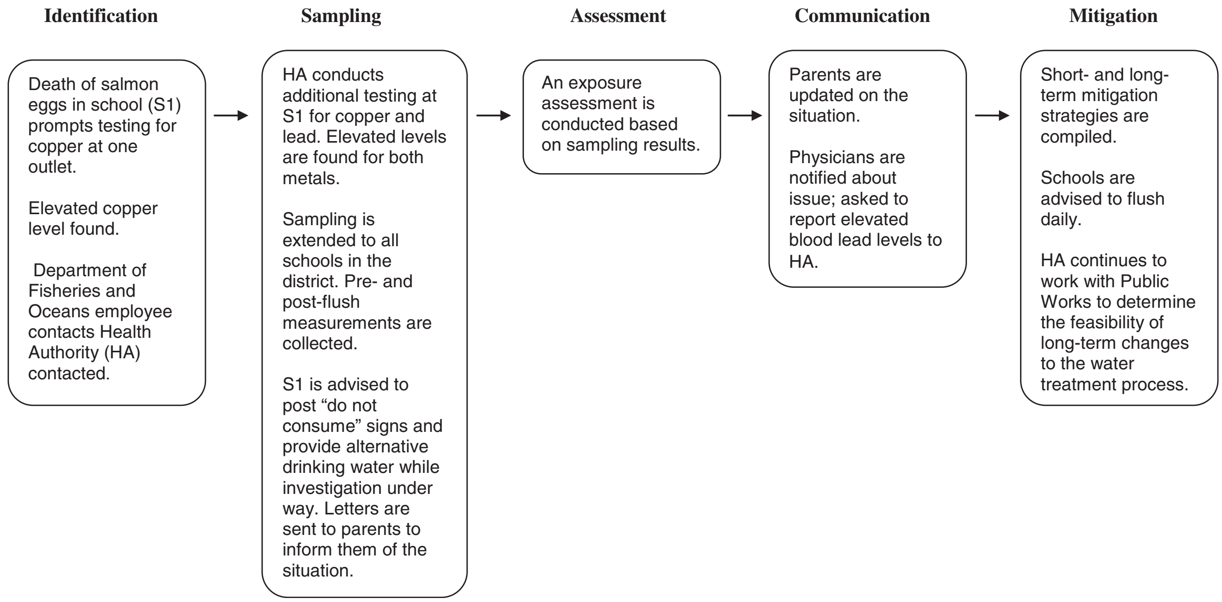

Fig. 1. Summary of actions taken at a school district to address elevated copper and lead concentrations in school drinking water.

Results showed that all four samples (pre- and post-flush) exceeded the drinking water guidelines for both metals.

Partners within the HA, including the Public Health Engineer, Drinking Water Planner, Public Health Nursing, and Communications, were notified of the elevated copper and lead concentrations at S1. The BC Centre for Disease Control (BCCDC) was contacted for guidance on further sampling required to assess potential exposures to students. Following consultation, the HA requested the school board do the following at S1:

(*i*) Post "Do Not Consume" notices to notify students and staff that water was unfit for drinking.
(*ii*) Cover all drinking water fountains in garbage bags to ensure they were not used.
(*iii*) Provide an alternative source of drinking water such as bottled water for students and staff and ensure bottled water was also used for cooking.
(*iv*) Implement a flushing protocol: flush dead-end[1] taps for five minutes, followed by a minimum 10-second flush of all drinking water outlets (Ontario Ministry of the Environment 2010).
(*v*) Provide the HA with a map detailing the school's plumbing, specifically dead ends, and information regarding any repairs to the plumbing system.

In consultation with BCCDC, the HA established a sampling regime to better assess exposures to copper and lead at S1; the regime was adapted from existing Health Canada and Ontario guidelines (Health Canada 2009; Ontario Ministry of the Environment 2010). Pre-flush and multiple post-flush samples (after 30 seconds, two minutes, and five minutes of flushing) were collected from water outlets in the school including all fountains and taps used for drinking or cooking. A sample from the water main entering S1 was also collected to determine if leaching of metals was occurring in the distribution system, school building, or both. A duplicate water main sample was sent to a second lab for quality assurance. Given concerns that other schools in the community may have also been affected, sampling was extended to all schools in the school district, which consisted of an additional two elementary and two secondary schools. Samples were collected at pre-flush and at five minute flush intervals from two outlets at each school. Information from the assessment was used to develop communication materials for parents as well as to inform mitigation options.

Assessment

General health effects of copper and lead

Copper is an essential nutrient but excess intake can cause adverse health effects. Drinking water containing 4–6 mg/L of copper can cause gastrointestinal effects including abdominal pain, nausea, and vomiting in healthy adults (Committee on Copper in Drinking Water National Research Council 2000). Few studies have investigated the long term health effects of excess copper intake, but limited evidence suggests individuals with abnormal copper homeostasis (e.g., Wilson's Disease) may be more susceptible to copper toxicity. No effects on liver function have been found in infants consuming water with 2 mg/L of copper (Olivares et al. 1998; Zietz et al. 2003; Zietz et al. 2003), although evidence for this vulnerable population is limited. In healthy persons, case reports suggest liver and kidney damage can occur at very high ingestion levels over long periods of time (e.g., 30 mg per day for 3 years) (Stern 2010).

Lead is a nervous system toxicant. Younger children may be particularly vulnerable due to their relatively higher exposures

[1]Dead ends are defined as mechanical joint caps used in piping systems where future expansion is anticipated.

and absorption rates and greater neurological vulnerability. Exposure in childhood has been associated with lower intelligence scores as well as behavioural disorders such as attention deficit disorder and antisocial behaviour (Bellinger 2008). During pregnancy, lead can be mobilized from maternal bone stores into the blood, eventually crossing the placenta and affecting fetal development (Gulson, Mizon, Korsch, Palmer, and Donnelly 2003). In adults, lead exposures have been linked to neurological, cardiovascular, and renal effects (Health Canada 2011b; National Institute of Environmental Health Sciences 2011).

Reference values for copper and lead

Because copper is an essential nutrient that can cause toxicity at elevated levels, recommended daily allowances (RDAs) and upper tolerable intake levels (ULs) have been developed (Table 1).

Canadian drinking water guidelines (DWGs) are also important references. The Canadian DWG of 1 mg/L for copper is an aesthetic objective based on taste, staining of laundry, and plumbing fixtures. This value is consistent with aesthetics-based guidelines set by other countries and is considered to be protective of health (Fitzgerald 1998; Health Canada 1992a). The World Health Organization (WHO) health-based guideline for copper in drinking water is 2 mg/L (World Health Organization 2004), whereas the US Environmental Protection Agency's (EPA) health-based maximum contaminant level goal is 1.3 mg/L (US Environmental Protection Agency 2012). Such health-based guidelines are intended to allow for consumption of typical amounts of water, food, and a nutritional supplement without producing acute gastrointestinal effects or exceeding the ULs.

There is no RDA/UL for lead because it has no known benefit. The Canadian DWG for lead in water is 10 μg/L (Health Canada 2011a). This value is partially based on a 1986 WHO provisional tolerable weekly intake (PTWI) for lead of 25 μg/kg. This PTWI was withdrawn in 2010 after research showed decreased IQ and increased blood pressure with lead intakes at 25 μg/kg per week. In their re-assessment, WHO concluded that there is no threshold for key adverse effects of lead and therefore, establishing a protective PTWI was not possible (World Health Organization 2011). However, the WHO guideline value for lead in drinking water remains 10 μg/L because of analytical and water treatment limitations (World Health Organization 2011).

Table 1. Health Canada recommended daily allowances (RDA) and upper tolerable intake levels (UL) for copper from all sources.

Age range (yr)	RDA (mg per day)	UL* (mg per day)
1–8	0.34–0.44	1–3
9–18	0.70–0.89	5–8
≥ 19	0.9	10

**The UL is the highest average daily nutrient intake level likely to pose no risk of adverse health effects to almost all individuals.*

Assessment of copper and lead exposures at schools

Samples collected from the water main entering S1 showed copper and lead concentrations below the DWGs, indicating the metals were leaching from school plumbing. Pre-flush copper and lead concentrations found at school outlets were used to estimate ingestion of copper and lead from school drinking water. Pre-flush values were considered to be most representative of actual exposures as schools were not flushing at the time of investigation. Exposures to elementary- and secondary-aged students were calculated separately because water intake differs by age. All samples were weighted equally, which meant S1 was over-represented with data collected from nine unique outlets compared with two at all other schools. The use of all samples reflected inter- and intra-variability of corrosion metals in school water. Estimated exposures were compared with tolerable daily intake levels for copper. In the absence of a health-based reference value for lead, estimated exposures were compared with reference conditions. Reference conditions were estimated using Health Canada's assumptions about typical daily lead intakes. Exposure estimates were only calculated for children, although it was recognized that staff would also be exposed to elevated copper and lead levels.

Copper

Table 2 presents pre- and post-flush copper levels and estimated total daily copper intakes from school drinking water for elementary and secondary school aged children.

The estimated intakes far exceeded the daily RDAs for copper for both elementary and secondary school aged children. In elementary schools, exposures also exceeded the lower limit of the upper tolerable intake levels that range from 1–3 mg per day for children between 1–8 years of age. Finally, several pre- and post-flush samples exceeded copper concentrations in water for which gastrointestinal symptoms have been reported in adults (4–6 mg/L) (Committee on Copper in Drinking Water National Research Council 2000).

As flushing is often recommended as a mitigation strategy to reduce concentrations of corrosion metals in water, the effectiveness of flushing to reduce copper concentrations from S1 drinking outlets was investigated (Figure 2). In general, longer flushing times resulted in lower copper concentrations, but the effectiveness varied widely by outlet. Even after five minutes of flushing, copper concentrations remained elevated above the DWG for four out of six drinking fountains and the kitchen tap. Lead levels at the school followed a similar trend, with two outlets having lead levels above the DWG after 5 minutes of flushing. A subsequent series of tests at S1 showed that 10 minutes of flushing was required to reduce copper and lead levels at all outlets to below the DWGs.

Table 2. Pre- and post-flush (5 min.) copper concentrations in school tap water and estimates of copper intakes at schools located in a BC community.

Type of school	No. of samples	Copper concentrations (mg/L)				Copper intake from school water (mg per day) using mean pre-flush values*
		Pre-flush		Post-flush		
		Mean	Range	Mean	Range	
Elementary ($n = 3$)	40	4.9	0.4–7.6	2.0	0.05–10.7	1.7
Secondary ($n = 2$)	8	3.2	2.2–4.0	4.3	0.5–7.0	1.5

**Water intakes of 0.34 L per day and 0.47 L per day for elementary and secondary students, respectively, were used. These values were based on the assumption that one-half of total daily water intake comes from school water; daily intake rates for all water of 0.68 L per day for children between 6 and 11 years (used here as an estimate for elementary school aged children) and 0.93 L per day for children between 16and 18 years (used here as an estimate for secondary school aged children) were used (U.S. Environmental Protection Agency, 2011).*

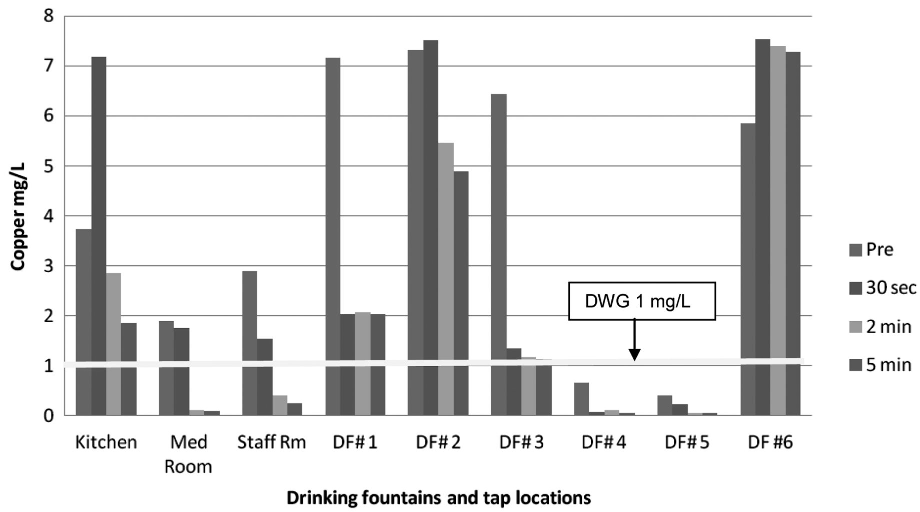

Fig. 2. Clearance of copper from sampled drinking water outlets in a school.

Lead

Table 3 presents pre-flush and post-flush lead levels and estimated total daily lead intakes from school drinking water for elementary and secondary school aged children.

We further expanded the assessment to include potential lead exposures from residential water in addition to school water for children aged 6–18 years. This was done to examine the implications of children living in neighbourhoods where plumbing and water characteristics are similar to that of schools. Case study estimates of lead intakes were calculated based on an assumption that all drinking water (school, home, and other) would have mean pre-flush lead levels equivalent to those found at schools. Other routes of lead exposure (air, soil, food) were included to provide an estimate of total daily lead intake. Health Canada provides total daily lead intake values for 2-year-old children and adults only, so reference conditions were estimated for children aged 6–11 years (elementary) and 12–18 years (secondary). By using Health Canada's reference lead concentrations in water (4.8 μg/L), food, air, soil–dust, and child-specific values for rates of water intake, we calculated reference conditions to represent "typical" intakes. Mean lead concentrations in water from our sampling (71.1 μg/L and for 94.5 μg/L for elementary and secondary schools, respectively) were used for case study scenarios. Table 4 shows that under the case study scenario, children's lead intakes were more than double the reference intakes, with water contributing close to 60% of total daily lead (Table 4). Under typical conditions, water contributes less than 10% of total daily lead. These estimates illustrate how exposure to lead concentrations in water, when greatly elevated, can substantially increase children's overall daily lead intake.

Communication

The HA maintained on-going communication and consultation with the Chief Medical Health Officer (CMHO), the local government, the Public Health Engineer, the school district, and the BCCDC. Additionally, community physicians and paediatricians were informed of the situation through a Physician's Bulletin and were asked to notify the CMHO of any elevated blood lead levels found in the community. At the time of this publication, no elevated levels had been reported to the HA.

On-going communication was also maintained with parents, students, and staff. After initial testing showed elevated copper and lead at S1, the CMHO issued a letter to parents and guardians of children attending the school to describe actions

Table 3. Estimated daily lead intakes from water consumed at school based on mean pre- and post-ush (5 min) samples collected in schools located in a BC community.

Type of school	Number of samples	Lead concentrations (µg/L)				Lead intake from school water (µg/day) using mean pre-flush values*
		Pre-flush		Post-flush		
		Mean	Range	Mean	Range	
Elementary ($n = 3$)	40	71.1	5.9–306	5.0	0.9–20.8	24.2
Secondary ($n = 2$)	8	94.5	12–191	12.3	1.2–21.0	44.4

**Water intakes of 0.34 L per day and 0.47 L per day for elementary and secondary students, respectively, were used. These values were based on the assumption that one-half of total daily water intake comes from school water; daily intake rates for all water of 0.68 L per day for children between 6 and 11 years (used here as an estimate for elementary school aged children) and 0.93 L per day for children between 16 and 18 years (used here as an estimate for secondary school aged children) were used (U.S. Environmental Protection Agency, 2011).*

Table 4. Estimated daily intakes of lead by pathway for elementary and secondary aged school children.

Pathway	Lead concentration	Elementary school aged child		Secondary school aged child	
		Health Canada estimates* µg/day (%)	Case study† µg/day (%)	Health Canada estimates* µg/day (%)	Case study† µg/day (%)
Air	0.06 µg/m^3	1.9 (4.4)	1.9 (2.2)	3.5 (5.5)	3.5 (2.4)
Water	‡Reference: 4.8 µg/L Case study: Elementary: 71.1 µg/L Secondary: 94.5 µg/L	3.3 (7.8)	48.5 (55.4)	4.6 (7.2)	87.9 (60.0)
Food	Various	30.1 (71.3)	30.1 (34.4)	48.4 (76.2)	48.4 (33.0)
Soil and dust	140 µg/g	7.0 (16.5)	7.0 (8.0)	7.0 (11.1)	7.0 (4.6)
Total Daily Lead Intake (µg per day)		42.2	87.5	63.5	146.8

**Values for lead intakes from air, food, and soil–dust were taken directly from Health Canada estimates (Health Canada, 1992b). Lead intakes from water were estimated using Health Canada's assumption of lead concentrations in water (4.8 µg/L) and estimates on daily water consumption rates. Rates of 0.68 L per day and 0.93 L per day for children aged 6–11 years (elementary school aged) and 16–18 years (secondary school aged), respectively, were used; these values represent 75th percentiles of the recommended values for drinking water ingestion rates for these age groups, as listed in the Child-Specific Exposure Factors Handbook by the US EPA (U.S. Environmental Protection Agency, 2011).*

†Lead intakes from air, food, and soil–dust were kept constant with Health Canada scenario conditions. Lead intakes from water were estimated using mean pre-flush lead concentrations (71.1 µg/L and 94.5 µg/L for elementary and secondary schools, respectively) and estimates of daily water consumption rates (same as Health Canada conditions).

‡For water, a reference concentration of 4.8 µg/L was used, this is the value used by Health Canada. In this case study, two values were used, the average lead concentration found in elementary schools and the average concentration found in secondary schools.

that were being carried out on an interim basis pending further investigation. An information sheet was distributed to parents to describe copper and lead exposures including potential sources, initial sampling results, general health effects, and mitigation strategies being considered by the school district. An updated information sheet was distributed to describe the exposure assessment and to advise parents to flush residential drinking water taps every morning for a minimum of five minutes. Parents were also advised to speak to a physician regarding health effects and the possibility of testing for blood lead levels if they had any concerns. Contact information for the local Environmental Health Officer (EHO), CMHO, and school district was provided in all communication materials. A handful of parents followed up with the HA for additional information. Local media reports did not appear to generate much interest in the community, which was in part thought to be due to the on-going communication with parents at the school.

Interestingly, the HA was contacted by the local fire hall after hearing media reports about elevated corrosion metals in school drinking water. The HA advised the fire hall to collect a pre- and post-flush (5 minute) water sample. Samples were above the DWG for both lead (pre-flush) and copper (pre- and post-flush). However, because sampling had been conducted after a 6-hour stagnant period, it was not considered to be representative of typical water usage in the hall and concerns about staff receiving elevated exposures were minimal. The HA recommend that dead-end taps be flushed for 5 minutes followed by a 10–30 second flush of all drinking water outlets after periods of stagnation.

Mitigation

Several options exist to lower copper and lead exposures in school drinking water. Mitigation strategies can help to lower metal levels in water, or to target the exposure.

Levels in water can be reduced by: (*i*) changing the pH of the water supply to a less corrosive level, (*ii*) adding corrosion inhibitors to water to increase scaling on pipes that provides a protective barrier between water and pipes, and (*iii*) removing lead- and copper-containing plumbing in buildings (Barn and Kosatsky 2011; Triantafyllidou and Edwards 2010). Exposures can also be lowered by: (*i*) implementing a flushing procedure to remove stagnant water from the system each morning, (*ii*) limiting use of school water to only cold faucets, (*iii*) terminating use of outlets where elevated levels have been found, (*iv*) installing point of use filters at each outlet, and (*v*) providing alternative drinking water sources such as bottled water to students and staff. Measures that lower metal levels in water are more effective in the long-term compared wtih targeting exposure alone, but they may be associated higher absolute or perceived costs. Mitigation strategies need to be tailored to each school.

In this case study, several recommendations were made by the HA including:

(*i*) All schools in the community should institute a flushing regime that would include a 10-minute flush of all dead-end taps, followed by a minimum 10-second flush of all drinking water outlets. This regime was adapted from the Ontario Ministry of Environment and Health Canada guidance. Flushing procedures are to be completed by staff prior to students' arrival at the school and are to be documented daily.

(*ii*) All schools should ensure that lead-containing drinking fountains and coolers are removed. The HA provided the school district with information about drinking water fountains and coolers that were recalled in the United States due to concerns over leaching from lead-containing parts (U.S. Environmental Protection Agency 2005). No schools in this district were found to have these particular fountains.

(*iii*) Treatment options should be considered by the community as a long-term strategy to reduce community-wide exposures to corrosion metals in drinking water. The HA discussed the aggressiveness of the drinking water with the Public Works Department, and an inspection of the water treatment facility was conducted by a Public Health Engineer and an EHO. At the time of this publication, the HA was developing a report to outline specific recommendations to the Public Works Department.

Discussion

This case study highlights the need to systematically monitor lead and copper in Canadian school drinking water. Copper and lead concentrations found here raised several concerns. Copper concentrations approached levels that have been linked to gastrointestinal effects in adults, indicating that acute health effects could have occurred in students and staff, although increased cases were not observed in the community. For lead, school water alone could have substantially contributed to a child's daily lead intake, and when equivalent concentrations in residential water were considered, water more than doubled typical total daily lead intakes. Given the serious health consequences of lead exposure during childhood and the effects that can occur even at low levels, reducing lead exposures should be a public health priority. Fortunately, this situation came to light despite the lack of monitoring in the school district. Without routine testing, other schools may unknowingly face similar water quality issues.

Identification of elevated corrosion metals in school water can signal the need to conduct broader testing in homes and other buildings in the same area. Although water use patterns may differ between schools and homes, water chemistry and plumbing characteristics, which largely influence lead leaching, tend to be similar. Additionally, informing parents and other community members about elevated levels in school water creates an opportunity to raise awareness about the importance of reducing lead exposures from other sources.

Mitigation measures to reduce corrosion metals in water differ in cost and effectiveness, and the best solution should be evaluated for each building. Flushing pipes before each school day is commonly recommended as a low cost strategy to reduce lead in school water. Here, samples collected at drinking water outlets at various time intervals showed that effectiveness of flushing varied widely between schools and between outlets in the same school. Flushing of dead-end taps, in addition to individual outlets, was found to help lower concentrations below DWGs. These findings have important implications for both the sampling strategies and the flushing recommendations provided to schools. Ontario remains the only province to in Canada to institute a routine monitoring program to limit lead in school water. However, under their current guidelines, schools are only required to take one water sample per school. As our results showed, concentrations can vary substantially within a school, and a one sample per building practice may lead to an inaccurate assessment of exposure. Additionally, current flushing protocols may need to be extended in duration and occur more frequently, a result that would require more time and attention from school staff, increasing the costs of such a program. Additional sampling needs to be conducted after a flushing program is implemented to ensure that levels are lowered and that they remain low throughout the school day. Finally, flushing must occur on a regular basis to lower exposures to corrosion metals among staff and students. Considering the time and effort required to flush each drinking water outlet, and the difficulty in ensuring compliance, other long term solutions should be considered to effectively lower copper and lead concentrations in school drinking water.

Conclusion

Findings here support the need for routine monitoring of drinking water in schools. Exposures to copper and lead in school drinking water can substantially increase daily intakes of these metals when levels are highly elevated, as well as when similar exposures exist in residential settings. Once identified, it is important to assess the extent of the contamination, communicate with partners throughout the investigation, as well as establish short- and long-term mitigation strategies. Where implemented as a short-term strategy, flushing programs should be tailored to each school as effectiveness of flushing, including duration and frequency, will vary from building to building. Flushing requires considerable staff time and must be performed on a regular basis to be effective and therefore, may not be suited as a long-term strategy to lower metal concentrations in school drinking water.

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