Investigating Sources of Elevated Lead in Drinking Water

by

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled “Investigating Sources of Elevated Lead in Drinking Water” by Brad McIlwain in partial fulfilment of the requirements for the degree of Master of Applied Science.

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Abstract

Lead exposure poses as a risk factor for various adverse health effects including intellectual delays, reduced IQ, and behavioural problems in children, as well as cognitive decline in adults. Lead enters drinking water through corrosion of leaded materials such as lead pipes, solder, and brass devices.

Three rounds of residential and non-residential lead monitoring were conducted to evaluate the corrosion control implemented by Halifax Water, and to identify sites with elevated lead concentrations. Follow-up testing was conducted at several sites to determine the sources of lead, and the factors that contributed to high lead release. Finally, a bench scale experiment was conducted to determine the impacts of plumbing flux on metal release.

The lead action level for residential testing was exceeded only in the round that was conducted during the winter. Lead concentrations were also higher in the winter rounds than the fall round of non-residential sampling. The seasonal lead variation was likely caused by fluctuations in aluminum residuals in the water leaving the plant. Frequency of use, age, and outlet manufacturer were factors that were associated with elevated lead levels.

Follow-up studies were conducted at several fountains to determine the source of elevated lead levels. These fountains typically contained several leaded components and received infrequent use. Fountains with leaded components that received high, regular usage had often provided samples with low lead levels.

Drinking fountains that were banned and recalled in the US for potentially containing lead lined cooling tanks were found at eight locations throughout the study area. It was found that three of the eight likely contained the lined cooling tanks. High lead levels were present in samples collected from these fountains, even at sites with frequent usage. Low-use sites with the lead lined tank produced the highest lead levels in this study. Fountains suspected of containing lead lined tanks were removed and replaced, and the lead levels were significantly reduced at these sites.

The impact of plumbing flux on metal concentrations was relatively short in duration, lasting only a week for most metals, with the exception of tin. Lead levels were found to stabilize under all flux conditions following roughly 40 L of flushing. Flux type was the main factor contributing to the elevated metals. The traditional petroleum flux was much more resistant to flushing than the water soluble flux, as it caused elevated tin levels for several weeks and a tacky flux deposition in the copper pipe remained even three months after the start of the experiment. The high amount of chloride from the flux was aggressive towards the copper corrosion, but it is unclear if this would have led to copper pitting corrosion.

List of Abbreviations and Symbols Used

ASTM	American Society for Testing and Materials
AL	Action Level
BLL	Blood Lead Level
CPSC	Consumer Product Safety Commission
CSMR	Chloride-to-Sulfate Mass Ratio
DO	Dissolved Oxygen
EDS	Energy Dispersive X-ray Spectroscopy
ICPMS	Inductively Coupled Plasma-Mass Spectrometry
JDKSWP	JD Kline Water Supply Plant
LCR	Lead and Copper Rule
LSR	Lead Service Line
MAC	Maximum Acceptable Concentration
NOM	Natural Organic Matter
NPC	National Plumbing Code of Canada
NSF	National Sanitation Foundation
ORP	Oxidation-Reduction Potential
PVC	Polyvinyl Chloride
SEM	Scanning Electron Microscope
TPF	Traditional Petroleum Flux
USEPA	United States Environmental Protection Agency
WSF	Water Soluble Flux

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Chapter 1: Introduction

Lead is a naturally occurring heavy metal, and because it is soft, provides moderate corrosion resistance, and has a relatively low melting point, its use dates back as far as the Roman Empire (Health Canada, 1992). Understanding of the toxic effects of lead also dates back to the Roman Empire (Nriagu, 1996). A significant increase in lead production began at the onset of the industrial revolution, as it began to appear in items such as tin-lead utensils, lead paints, and gasoline; however, the use of lead peaked in the 1970's due to the bans on its use in paint and gasoline (Skerfving and Bergdahl, 2007).

As a result of banning the use of lead in gasoline and paint, blood lead levels (BLLs) in North America have decreased significantly since the 1970's, and child deaths due to lead poisoning have essentially been eliminated; however, as a result of its various historical uses, it continues to persist in our environment (Lanphear, 2007). Despite the significant reduction of children's BLLs, new research is finding that there is no safe lead level. The Centers for Disease Control and Prevention level of concern for children's BLL is 10 µg/dL, yet concentrations below this level have been associated with reduced IQ (Canfield et al, 2003). Problems due to low levels of lead exposure are not simply confined to children, whom it poses a risk factor for intellectual delays and behavioural problems, but also with adults as it is a risk factor for disability and cognitive decline (Lanphear, 2007).

Current sources of lead include the air, dust, soil, food and drinking water (Skerfving and Bergdahl, 2007). Drinking water has been recognized as a source of lead exposure since the middle of the 19th century, prior to leaded gasoline and the extensive use of lead paint; and currently it is estimated in to contribute to approximately 20% of lead exposure in North America (Troesken, 2006; USEPA, 2005). Efforts to reduce lead exposure from drinking water in Canada and the US have been successful, including: the development and implementation of stricter and more effective guidelines and regulations, such as the Lead and Copper Rule (LCR) (Edwards and Dudi, 2004); banning the use of lead service pipes, solders, and fluxes (Health Canada, 2007; USEPA, 2006); and development of non-leaded brasses with less than 0.25% Pb by mass content (Sandvig et al, 2009). However, cases of elevated BLLs in children continue to be associated with drinking water lead. A recent example that gained notoriety was the crisis in Washington, DC, when a change of disinfectant triggered high lead problems that were associated with elevated BLLs in children (Brown et al, 2011; Edwards et al, 2009). In the case of the crisis in Washington, the biggest problem was with houses that contained lead service lines, which would have been houses constructed before 1986.

Drinking water lead problems are not limited to older plumbing, as several occurrences of high lead have been attributed to brass devices in new buildings (Elfland et al, 2010). Both cases occurred in non-residential buildings, including an academic institutional building and a school. In both cases flushing was implemented as an unsuccessful remedy. Testing for lead in non-residential buildings such as schools, daycares, and institutional buildings is imperative owing to: the high population of children, who are at a particular risk of the toxic effects of elevated lead compared to adults (Canfield et al, 2003); irregular fountain and faucet usage patterns, which allow long periods of stagnation throughout the day as well as over entire weekends (Barn and Kosatsky, 2011); and long series of pipes and outlets, such as fountains, which may contain various leaded components (USEPA, 1990). Research related to the corrosion of lead in distribution systems has increasingly grown in the last 20 years due to the real and severe health risks, which result from contaminated drinking water (Hu et al, 2010); however, more research is required to determine the degree of lead exposure from drinking water in schools and institutional settings. Drinking water testing in schools in Canada is currently only required in the Province of Ontario and corrective measures for exceedences are the responsibility of the school, and not the responsibility of the utility (Barn and Kosatsky, 2011). Canadian data is therefore quite limited and the extent of the problem is not yet understood. In order to develop solutions to reduce exposure, the significant sources of exposure must be identified and the settings that exacerbate these problems must be understood.

1.1 Research Objectives

The goal of this research was to identify sources of lead in residential and non-residential plumbing systems, and to identify the circumstances that tend to result in the greatest metals release. To accomplish these objectives, three tasks were developed:

1. Conduct several rounds of lead monitoring and compare the infield testing results to the action levels (AL) outlined in the Health Canada Guidance (2009) for both residential and non-residential buildings.
2. Follow up on sites with high lead discovered through the monitoring rounds and determine the cause of excess lead as well as under which circumstances lead and metals problems are exacerbated.
3. Investigate the effect of soldering flux on metals release from an inline brass plumbing device galvanically connected to copper piping.

1.2 Organization of Thesis

This thesis is organized in six chapters, where chapters three, four, and five are papers which present the results of three different studies.

Chapter 1 provides a brief introduction to the problem that was investigated during this thesis, explaining the health effects of lead ingestion and the issues related to lead in drinking water. This chapter also outlines the overall objectives of this thesis, and summarizes the organization of the document.

Chapter 2 provides a background of corrosion principles and discusses the mechanisms by which lead enters drinking water and the factors affecting lead levels.

Chapter 3 is a paper addressing a lead monitoring program, which was conducted at an academic institution in Halifax, NS. The results from the campus monitoring program were used to gain an overall understanding of the corrosive behaviour of the distribution system in Halifax, and to identify limitations of the current corrosion control measures. The monitoring also helped to identify specific lead risks in the larger buildings, which was the focus of the paper presented in **Chapter4**. This paper presents the findings of a study of drinking water fountains which contributed to elevated lead levels. Several fountains were studied in detail to determine the specific sources of lead, and recommendations were made in order to reduce major sources of lead exposure at the academic institution.

Chapters 5 presents the results of a study examining the effect of plumbing flux on metals release in new plumbing installations. The bench experiment focussed on the long term effects of plumbing flux under low-flow conditions.

Chapter 6 provides recommendations for future research as well as summarizes the conclusions developed from this research.

Chapter 2: Background

2.1 Principles of Corrosion

Corrosion is an undesirable and spontaneous electrochemical reaction that requires the presence of an anode, a cathode, an internal circuit, and an electrolyte, and results in the destruction of a metal through redox reactions (Snoeyink and Wagner, 1996). A redox reaction is a reaction which must involve both oxidation and reduction half-reactions concurrently, and the number of electrons associated with the oxidation must be equal to the number of electrons associated with the reduction (Petrucci et al, 2002). An example of a redox reaction is demonstrated in Figure 2.1, which illustrates the result of dipping a zinc rod in an aqueous copper solution (Petrucci et al, 2002). The zinc is oxidized, releasing electrons and increasing its oxidation state to 2+, and in the process releasing zinc ions into solution. The Cu^{2+} ions are drawn to zinc rod where they are reduced from 2+, gaining an electron and forming a solid deposit on the zinc rod. The removal of Cu^{2+} ions is demonstrated by the colour change of the solution from blue to clear.

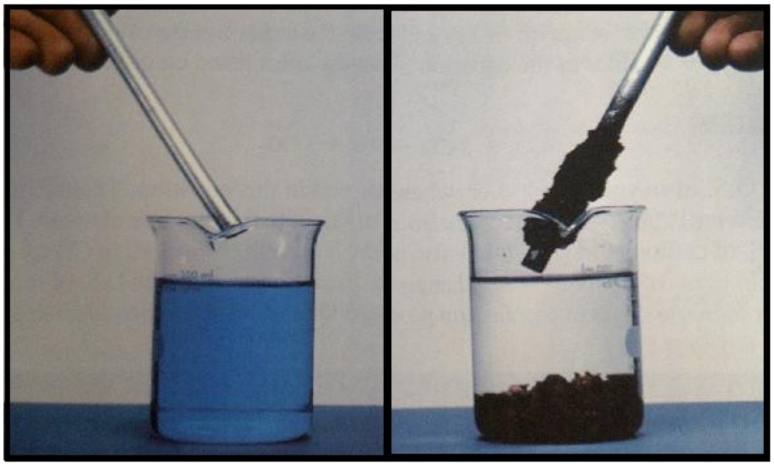

Figure 2.1: Zinc electrode immersed in an aqueous copper solution (Petrucci et al, 2002)

The oxidation-reduction half reactions are described by equations [2.1a] and [2.1b].

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-} \qquad [2.1a]$$

$$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s) \qquad [2.1b]$$

In a corrosion reaction, oxidation of a metal takes place at the anode, releasing an electron through the internal circuit towards the cathode, and releasing a positively charged ion in the process which also tends to migrate towards the cathode (Snoeyink and Wagner, 1996). The electron is discharged at the cathode to an electron acceptor such as O_2, H^+, or HOCl by the reactions presented in equations [2.2, 2.3, 2.4]. Negative ions generated at the cathode tend to migrate towards the anode to maintain neutrality of the solution.

$$2H^{+}+2e^{-}\rightleftharpoons H_2 \qquad [2.2]$$

$$O^{2}+2H_2O+4e^{-}\rightleftharpoons 4OH^{-} \qquad [2.3]$$

$$HOCL+2e^{-}\rightleftharpoons Cl^{-}+OH^{-} \qquad [2.4]$$

The anode and cathode in a corrosion cell is determined by the standard electrode potentials of the electrodes involved. The standard electrode potential, E°, provides the electric potential of a given substance at its standard state, and is determined by measuring the potential difference, or voltage, of the electrode as it is connected in a voltaic cell with the standard hydrogen electrode (Petrucci et al, 2002). An example illustrating the determination of E° for a copper electrode is illustrated in Figure 2.2.

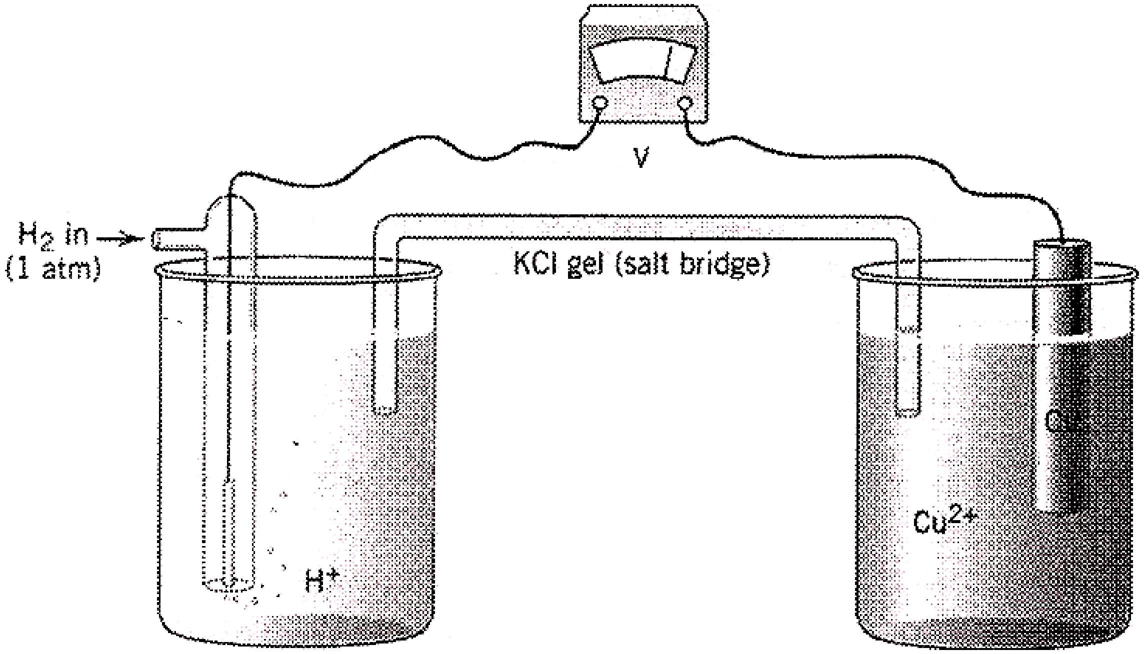

Figure 2.2: Determining the standard electrode potential of copper using standard hydrogen electrode (Droste, 1997)

In a corrosion reaction, the standard cell potential can be determined from subtracting the standard electrode potential of the anode from that of the cathode. Standard electrode potentials provide information related to which electrode is likely to be reduced and which electrode is likely to be oxidized, as the anode has the more negative standard electrode potential (Jones, 1996). The list of standard electrode potentials presented in Table 2.1 provides data for materials which may be present in a common water distribution system. The materials are presented in order such that those at the top are more likely to be cathodic whereas the materials at the bottom are more likely to be anodic. Electrode potentials offer a simplified perspective and may not provide an accurate prediction of which material will behave anodically and which will behave cathodically depending on other factors. If a metal has reacted to form a soluble complex, the potential may change and consequently its behaviour in an electrochemical cell may change from anodic to cathodic, relative to the other electrode (Revie and Uhlig, 2008). Depending on the types of brass and types of water, brass may behave as either a cathode or an anode to copper (Triantafyllidou et al, 2007). The general behaviour is such that the greater the differences in electrode potential the greater the rate of galvanic corrosion (Snoeyink and Wagner, 1996).

Table 2.1: Relevant standard electrode potentials adapted from (Petrucci et al, 2002)

	Reduction Half-Reaction	E° (V)
	$PbO_2\,(s) + 4H^+\,(aq) + 2e^- \rightarrow Pb^{2+}\,(aq) + 2H_2O\,(l)$	+1.455
	$OCl^-\,(aq) + H_2O\,(l) + 2e^- \rightarrow Cl^-\,(aq) + 2OH^-\,(aq)$	+0.890
	$Fe^{3+}\,(aq) + e^- \rightarrow Fe^{2+}\,(aq)$	+0.771
	$O_2\,(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-\,(aq)$	+0.401
More Cathodic ↑ ↓ More Anodic	$Cu^{2+}\,(aq) + 2e^- \rightarrow Cu\,(s)$	+0.340
	$SO_4^{2-}\,(aq) + 4H^+\,(aq) + 2e^- \rightarrow 2H_2O\,(l) + SO_2\,(g)$	+0.170
	$Sn^{4+}\,(aq) + 2e^- \rightarrow Sn^{2+}\,(aq)$	+0.154
	$2H^+\,(aq) + 2e^- \rightarrow H_2\,(g)$	0.000
	$Pb^{2+}\,(aq) + 2e^- \rightarrow Pb\,(s)$	-0.125
	$Sn^{2+}\,(aq) + 2e^- \rightarrow Sn\,(s)$	-0.137
	$Fe^{2+}\,(aq) + 2e^- \rightarrow Fe\,(s)$	-0.440
	$Zn^{2+}\,(aq) + 2e^- \rightarrow Zn\,(s)$	-0.763
	$Al^{3+}\,(aq) + 3e^- \rightarrow Al\,(s)$	-1.676
	$Mg^{2+}\,(aq) + 2e^- \rightarrow Mg\,(s)$	-2.356
	$Na^+\,(aq) + e^- \rightarrow Na\,(s)$	-2.713

An example of a typical corrosion reaction of a lead pipe in a water distribution system is shown in Figure 2.3, where the lead pipe is the metal which undergoes corrosion and the dissolved oxygen (DO) in the water is the oxidant. Various types of corrosion exist but those most frequently encountered in water distribution systems include: uniform, pitting, and galvanic.

Uniform and pitting corrosion may both take place on a single metal when given regions of a metal transition between anodic and cathodic behaviour. When this occurs, the metal is described as a polyelectrode. The distances between the anode and cathode, and the magnitude of the potential difference between the anode and cathode influences the type of corrosion which occurs (Snoeyink and Wagner, 1996). Uniform corrosion occurs when the distances and potential differences between the anode and cathode are small and the movement of these regions results in uniform material losses along the surface (Snoeyink and Wagner, 1996). The anodes and cathodes involved in uniform corrosion shift constantly from one microscopic site to the next, resulting in a relatively uniform metal loss across the surface. Anodic sites which result in uniform corrosion may occur as a result of several factors: imperfections in a metal may result in potential differences between adjacent surfaces; films may develop along pipe walls allowing for transport of electrons and ions; and differences in concentrations of oxidants and reductants in the water may create potential differences (Snoeyink and Wagner, 1996). When the anodic and cathodic areas are more separated and large potential differences exist, then pitting corrosion and irregular deposition may occur.

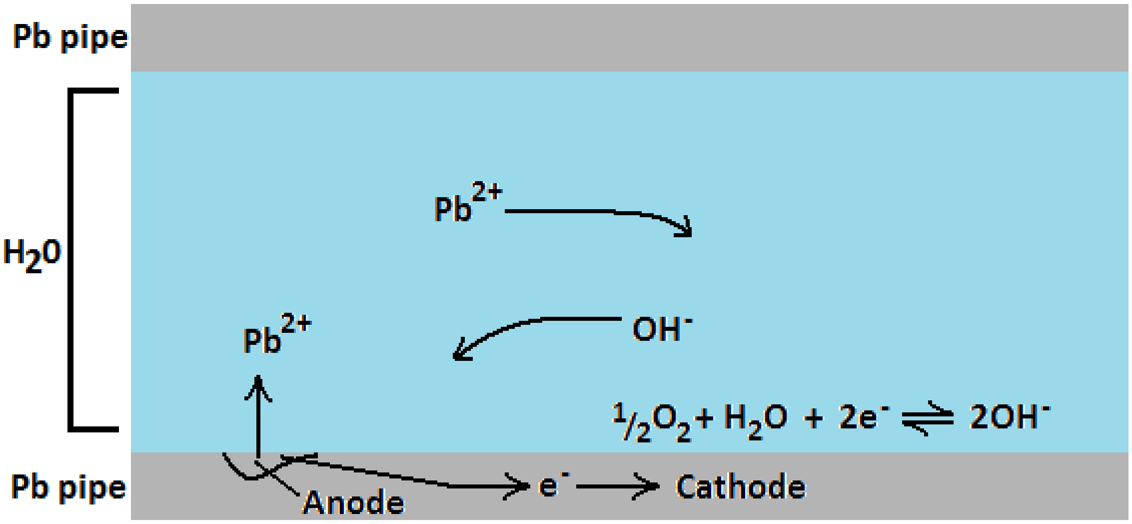

Figure 2.3: Schematic diagram of corrosion cell of a lead pipe in a distribution system (adapted from (Snoeyink **and Wagner**, 1996)

Galvanic corrosion occurs when multiple dissimilar metals are involved. In galvanic corrosion, the anode will be preferentially corroded whereas the other metal may undergo cathodic protection. Surface area ratios of anode and cathode also may have significant effects on corrosion rate. Larger ratios of cathode to anode concentrate galvanic corrosion to a small area, increasing rate of penetration into the metal (Jones, 1996). Other factors which can affect the rate of galvanic corrosion include distance between electrodes as well as water conductivity.

Corrosion which results from the heterogeneous nature of the aqueous solution, known as concentration cell corrosion, is one other form of corrosion which may occur in distribution systems. This is a local type of corrosion which often occurs due to differences in DO along the surface of the pipe, where regions in contact with high O_2, become cathodic and the regions in presence of lower O_2 become anodic (Snoeyink and Wagner, 1996).

2.2 Sources of Lead

The main contributor of lead in drinking water systems is through corrosion of leaded materials in the treatment plant, distribution system, service lines, or in premise plumbing (Dudi et al, 2005). Although lead may occasionally be found in source waters, it is usually at very low concentrations and can be readily removed at the water treatment plant (USEPA, 2006). Leaded materials may include valve parts and gaskets at the treatment plant and within the distribution system; lead pipes; 50:50 lead-tin solder; and brass fixtures and faucets (Health Canada, 2009). The National Plumbing Code of Canada (NPC), which is used as the foundation for plumbing regulations in all provinces and territories, has made efforts to eliminate sources of lead in drinking water distribution systems. The steps taken include the ban of the use of lead pipes in service lines in 1976, limiting lead content of solders from 50% to 0.2% in 1986, and eventually prohibiting the use of any lead solders in drinking water systems in 1990 (Health Canada, 2009). Despite these efforts, cases of lead contamination in drinking water continue to occur due to contributions from lead solders and service lines in older buildings; lead in brass devices;

and through continual release of lead from corrosion scales with built up lead deposits in premise plumbing (McFadden et al, 2011).

Lead Service Lines. An illustration of a typical residential water service connection is show in Figure 2.4. The supply pipe, also referred to as a service line, is the pipe which connects the home plumbing to the water main. The service line comprises of two sections: the public portion, which is owned by the utility and connects the water main to the property line; and the private portion, which extends from the property line into the residence and is the possession of the property owner. Newer water service lines in Canada are made of copper or polyethylene tubing; although prior to 1975, the use of lead pipes was common (Health Canada, 2009). In the United States, the use of lead pipes continued into the 1980's and it is estimated that over 3 million continue to exist (Boyd et al, 2004). Depending on site conditions such as the length of the service line, presence of lead solder, types of brass devices used in building plumbing, and the water quality, the service line is estimated to contribute roughly 50 – 75% of the mass of lead measured at the tap at sites with lead services (Sandvig et al, 2008).

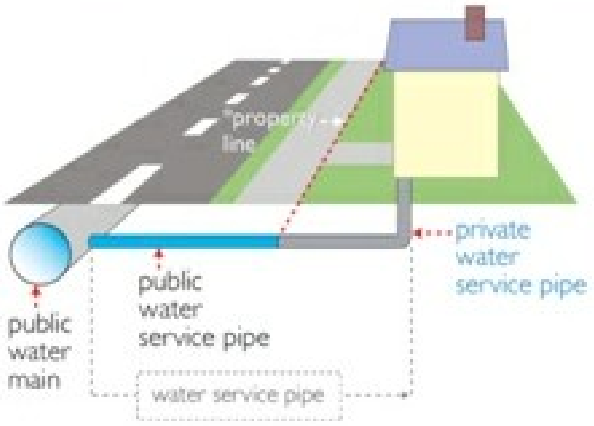

Figure 2.4: Schematic diagram of typical residential water service (DC Water and Sewer Authority, 2012).

Lead service line (LSL) removals are a common practice implemented by utilities during water main renewal projects, and in the US are required under the LCR by utilities which continue to exceed the 90th percentile lead action level after optimizing corrosion control at the locations which have first draw lead concentrations above 15 µg/L (Boyd et al, 2001). During a LSL replacement, a utility will replace the portion of lead tubing which is situated on the public side of the property line with copper tubing. Occasionally, utilities will pay for the entire removal of a LSL, including the portion which is situated on the private side of the property line (Wilczak et al, 2010); however, the removal of the service pipe, extending from the property line to the meter, is typically the responsibility of the property owner, and due to the costs of replacing the private portion, owners are often hesitant or unwilling to remove their portion of the LSL (AWWA, 2005).

When the private portion of lead pipe is kept in place and the public portion is replaced, the configuration is known as a partially replaced service pipe. Many utilities in Canada use a copper tube which is connected upstream of old lead tubing. Although a partial replacement reduces the surface area of lead in contact with water, cases have found that the risk of elevated BLLs associated with LSL exposure is not significantly decreased (Brown et al, 2011). In many cases, partial replacements may actually worsen lead levels compared to those resulting from full length lead pipes. Increases in lead concentrations as a result of partial replacements have been observed in short-term and long-term lead release (Triantafyllidou et al, 2011; Boyd et al, 2004; Schock et al, 1996). In a study of simulated partial lead pipe replacements, Boyd et al (2004) found that the elevated lead resulting from disturbance to the corrosion scale during the replacement process decreased below the 15 μg/L AL following 15 – 30 minutes of low flow flushing. Further testing revealed that a continuous flow flushing pattern was more effective than an intermittent flow pattern in stabilizing the total lead concentrations. Long-term increases in lead concentration due to partial service replacements are caused by the creation of a galvanic cell between the old lead and new copper (Triantafyllidou et al, 2011). The extent to which galvanic action may increase lead release is dependent on various factors including water chemistry – specifically the chloride-to-sulfate mass ratio (CSMR) – and flow patterns.

Lead Solders. Soldering is a joining method, commonly used in plumbing, which involves a molten metal filler which reacts to form a bond with the plumbing components (Humpston and Jacobson, 2004). Lead solders were ultimately banned from use in drinking water plumbing in Canada in 1990 (Health Canada, 2009); however, they are still present in older plumbing systems and the possibility of their illegal use exists because leaded solders are available from typical hardware stores. The contribution of solders to lead concentrations measured at the tap is dependent on various factors such as the plumbing age; the length of piping and amount of joints present; and water quality characteristics (Lee et al, 1989). The direct connection between copper piping and lead solder also creates a galvanic connection which can cause lead from solders to be especially problematic.

Brass. Brasses used in drinking water plumbing must be lead free; however, the definition of "lead free" permits these brasses to contain up to 8% lead by mass. Upcoming changes to the SDWA in the US will require lower lead levels in brass, but these changes won't be enacted until January 2014. Common devices made of brass include faucets, valves, fixtures, refrigerated water coolers, and drinking water fountain bubbler heads. The contribution of lead to drinking water from brass devices is well documented, particularly in new plumbing installations (Elfland et al, 2010; Boyd et al, 2008b; Boyd et al, 2008c). In a study of drinking water in a new academic institutional building, Elfland et al (2010) found inline ball valves containing more than 20% lead by mass on the water-exposed surface. These ball valves were determined to be the prominent cause of the high lead which was being investigated, and which was not alleviated through repeated attempts at flushing.

Contributions of lead from brass devices are not simply limited to new installations. A study was conducted comparing LCR data of houses with all plastic plumbing where the major source of lead was brass, with houses which were considered "high risk" by the United States Environmental Protection Agency (USEPA), due to the presence of lead solder and service lines (Kimbrough, 2007). Although the lead concentrations in the sites with all plastic plumbing were found to decrease with time, the contribution from brass did not decrease to an insignificant level. Additionally, the houses with all plastic piping initially had higher lead results than the high risk houses, and even after the levels decreased in the all plastic homes, it was only to a level which was comparable to the high risk houses. These findings supported an earlier investigation of LCR monitoring data where brass was found to be a major source of both lead and copper at sites which were considered high risk, with lead service lines and solder (Kimbrough, 2001).

The USEPA adopted the American National Standards Institute/NSF Standard 61, section 8 and section 9, as performance standards for new brass plumbing devices containing lead. The section 9 standard pertains to end use devices such as faucets and drinking water fountains, while the section 8 standard pertains to inline devices such as meter couplings, water meters, and valves. Products which pass section 9 are recognized by the USEPA to limit lead release and are labelled as lead free, despite having a possible lead content of up to 8% (Sandvig et al, 2009; Dudi et al, 2005). The use of non-leaded brass, which contains less that 0.25% lead by mass, is an effective method of reducing lead contamination. Costs of such brasses are reasonably higher than for leaded brass; however, when total replacement costs, including labour, equipment and other expenses, are considered, the non-leaded brass costs are at most 5% higher (Sandvig et al, 2009).

Passing the ANSI/NSF standards suggests that a product will not lead to excessive lead corrosion; however both section 9 and section 8 have been criticized for their accuracy. Dudi et al (2005) performed an assessment of the ANSI/NSF Standard 61, section 8, to evaluate the standard’s ability to protect public health. The study concluded that section 8 did not offer a rigorous level of protection against lead contamination. It was found that a phosphate buffer, added to pH 5 testing water, served to reduce lead corrosion, rendering the water less aggressive than many tap waters, and that a small device made of pure lead could in fact pass the section 8 standard. Although less criticism has been directed at the section 9 standard, some issues have been reported. It has been suggested that the pass/fail criterion should be redefined to account for ranges of corrosiveness of real waters and that the synthetic test water should be representative of more corrosive water, rather than of typical water supplies (Triantafyllidou et al, 2007). Recently, the NSF/ANSI Standard 61 Joint Committee have begun implementing changes to their testing protocol (Elfland et al, 2010).

Factors which affect lead release. Various factors affect the rate of lead release and the levels of lead measured at the tap. Extensive research has been conducted to determine the impacts of various water quality parameters and plumbing factors which impact lead concentrations in drinking water. The means by which these factors affect lead levels is quite complex, and depending on the nature of corrosion scales formed in a distribution system, and the qualities of the treated water, changes of a single element could potentially increase or decrease lead levels. A simple example of this would be a change of disinfectant type from free chlorine to chloramines. Chloramines are weaker oxidants, and would therefore be expected to decrease corrosion rates; however, in systems where tetravalent lead corrosion scales are present, the reduced oxidation reduction potential (ORP) of the water could cause a shift to the more soluble divalent lead species, consequently causing elevated lead levels at the tap (Boyd et al, 2008a).

Factors which affect lead release include: chemical factors such as pH, alkalinity, hardness, and CSMR; and physical factors such as flow rate, temperature, and stagnation time. These factors are briefly explained in Table 2.2, along with how they may impact lead release in water supplied by the JD Kline Water Supply Plant (JDKWSP).

Table 2.2: Impacts of water quality and plumbing factors which affect lead levels at the tap

Factor	Effect on Lead Release	References
Chemical		
pH	• Affects the solubility of corrosion by-products • Increased pH typically decreases solubility of by-products • Optimum pH for divalent lead control around pH 9.8 • Effects of pH related to alkalinity	(Schock et al, 1996; Dodrill et al, 1995)
Alkalinity	• Controls the ability of a water to maintain a consistent pH • Effect on lead release expected to be dependent on type of corrosion scales present • A survey of US utilities demonstrated that lead levels were lower at utilities with alkalinity levels between 30 - 74 mg/L as $CaCO_3$, compared to utilities below 30 mg/L as $CaCO_3$; at sites below 30 mg/L as $CaCO_3$ inhibitors reduced lead release	(Schock et al, 1996; Dodrill et al, 1995)
CSMR	• CSMR above 0.2 considered a serious concern; increasing to 1.0 increases lead release from galvanic connections; further increases above 1.0 may have lesser adverse effects • Elevated CSMR results in accelerated galvanic corrosion of lead pipe to copper or lead solder to copper pipe • High CSMR may create highly corrosive microenvironment with very low pH and high concentration of chloride compared to sulfate • Chloride can react to form soluble complexes, whereas sulfate may form protective scale	(Nguyen et al, 2011; Nguyen et al, 2010)
Disinfection Residual	• Presence of corrosion scales affects lead release due to disinfectants • On new pipes where scales haven't developed, chlorine increases corrosion of lead due to the increased ORP	(Boyd et al, 2008a; Lytle et al, 2005; Cantor et al, 2003)

Factor	Effect on Lead Release	References
Chemical		
Disinfection Residual *cont.*	• Free chlorine is a stronger oxidant than chloramines; chlorinated water therefore has a higher ORP than chloraminated water • Water disinfected with free chlorine may have persistently high ORP which then may lead to the development of Pb(IV) corrosion scales which have very low solubility • When Pb(IV) scales are present, depletion of free chlorine may revert the lead to the reduced Pb(II) form	
NOM	• Presence of NOM can break down large colloidal particles of lead corrosion products, and increases presence of soluble lead • NOM can cause increases in both short term and long term lead release from brass • The effects of NOM are most noticeable in the low ranges of DOC from 0 – 2 mg/L • NOM participates in the reduction of Pb(IV) solids; this is affected by NOM concentration and not by NOM type	(Dryer et al, 2007; Korshin et al, 2005; Korshin et al, 2000)
Corrosion Inhibitor	• Phosphate corrosion inhibitors are commonly used in either the form of orthophosphate or polyphosphate • Inhibitors are dosed in order to develop a film of insoluble lead phosphate compounds on the pipe surface • Cases of increased soluble lead and copper levels due to polyphosphate have been reported • Dosing of orthophosphate is understood to reduce soluble lead • Orthophosphate can inhibit the formation of the protective Pb(IV) scale which would otherwise be expected based on water quality conditions	(Lytle et al, 2009; Nadagouda et al, 2009; Edwards et al, 2002; McNeill et al, 2002)

Factor	Effect on Lead Release	References
Physical		
Flow rate	• High flow can cause increased lead release in either dissolved or particulate form by either accelerating mass transfer of lead from pipe scale or by physically destabilizing the scale • Increased velocity may increase corrosion rates by increasing the supply of oxidant to cathodic surfaces • High flow rates may cause spikes in lead particulate concentrations	(Cartier et al, 2012a; Sarver et al, 2011; Xie and Giammar, 2011)
Temperature	• The effect of temperature on lead release in drinking water is complex • Increasing temperature is likely to increase corrosion rates • Solubility of corrosion by products may either increase or decrease with changes to temperature, so the effects of temperature could vary based on scale mineralogy • A survey of US utilities found that lead levels were not significantly greater during warm water conditions when compared to the cold water conditions • Hot water has been found to significantly increase lead release from brass	(Sarver et al, 2011; Dodrill et al, 1995; Schock, 1990)
Galvanic connection	• Examples of increased lead release owing to galvanic connections are well documented • Galvanic connections are formed when dissimilar metals such as lead and copper are directly connected • The extent of the effects of galvanic connections are dependent on CSMR and stagnation time • High CSMR is associated with increased lead leaching and galvanic corrosion • Galvanic current (often measured in studies) cannot predict lead levels; however, it provides a direct measure of galvanic corrosion	(Nguyen et al, 2011; Triantafyllidou et al, 2011; Nguyen et al, 2010)

Factor	Effect on Lead Release	References
Physical		
Stagnation time	• In new lead pipes, equilibrium may require as little as eight to 24 hours • Older pipes often take much longer to reach equilibrium • In a study examining the effect of stagnation time on lead release, pipes which were aged for roughly 170 days and 460 days both exhibited similar stagnation curves: releasing the greatest amount of lead (50-70%) in the first 10 hours, but continued to release lead for as much as 90 hours. • In certain cases, extended stagnation times could actually decrease lead levels through reattachment of particles to pipe walls	(Edwards et al, 2002; Lytle and Schock, 2000; Schock, 1990)
Age of pipe	• In older pipes, solubility equilibrium may take far longer than in new pipes, which may reach equilibrium in as little as 24 hours • A study examining lead release from lead pipes of varying ages found that soluble lead levels decreased significantly with aging, but to a lesser extent than particulate lead did	(Edwards et al, 2002; Schock, 1990)

Chapter 3: Lead Monitoring Program

3.1 Introduction

Lead typically enters drinking water through corrosion of leaded materials in the distribution system, service lines, or in premise plumbing, and is typically not found in surface source waters (USEPA, 2006; Dudi et al, 2005). Examples of corrosion control for the purposes of reducing iron corrosion date back to the 1930's (Wilczak et al, 2010); however, measures dedicated to controlling lead corrosion are much more recent. While surveys of lead service pipe use date back as far as the 1920's in the US, the importance of removing lead services was deemed low by water suppliers in studies as recent as 1985 (Schock et al, 1996). Typically, concerns regarding the health risks of lead-contaminated drinking water have shadowed developments within the medical field, which have progressively connected neurological impairment with low exposure levels (Maas et al, 2005).

The "Federal Lead Ban" of 1986 in the Safe Drinking Water Act was the first major initiative to control lead in drinking water in the US (Maas et al, 2005). The Lead Ban required solders and fluxes to contain below 0.2% lead by mass and brasses were required to contain below 8% lead by mass. The ban was followed by the Lead Contamination Control Act (LCCA), which was enacted in 1988, for the purpose of reducing lead exposure from drinking water in schools and daycare facilities (USEPA, 2006). The Act required the development of guidelines for testing in schools; mandated the USEPA to release a list of drinking water coolers which contained lead; ordered the manufacturers and importers of water coolers with lead lined tanks to repair, replace, or provide refunds for these coolers; and established legal penalties for the manufacture and sale of leaded cooling tanks (USEPA, 2006; Maas et al, 2005). Unfortunately, the monitoring and reporting requirements developed from the LCCA were not enforceable, so monitoring of lead in schools varies by state. Finally, the Lead and Copper Rule (LCR) was promulgated in 1991, requiring utilities to determine the level of lead exposure within their systems. LCR requires that monitoring is conducted at a number of higher risk houses, dependent on the population served by the utility, and if 10% or more of the sites have lead concentrations greater than 15 μg/L, the utility is required to notify the public of their potential exposure to high lead and develop corrective measures to reduce the corrosivity of the water (USEPA, 2010).

In Canada, corrosion control for purposes of reducing lead exposure has an even shorter history. Drinking water in Canada is provincially regulated; therefore, lead corrosion control and monitoring varies throughout the provinces. In Ontario, regulations were developed which require monitoring of both residential and non-residential buildings, as well as regulations exclusively for monitoring lead in schools and daycare centres (Government of Ontario, 2010a; Government of Ontario, 2010b). In fact, Ontario is the only province which regulates testing in schools (Barn and Kosatsky, 2011).

Ontario's residential monitoring is based on the 90th percentile concentration, much like the LCR testing; however, sampling is conducted following 30 minutes of stagnation, and at each site two consecutive one litre samples are collected and the higher concentration is that which is recorded (Government of Ontario, 2007).

Lead monitoring in Ontario schools must be conducted at one location in every school on an annual basis, and may be reduced to once every three years if the standard was not exceeded in samples collected in the previous two years (Government of Ontario, 2009). Two samples are collected during each monitoring period: a standing sample and a flushed sample. If the standing sample has a lead concentration above the 10 ug/L standard, schools are required to be flushed every day before the school is opened. If the flushed sample is above the standard, further testing is required and corrective actions may be necessary.

The Province of Nova Scotia employs Health Canada's (1996) "Guidelines for Canadian Drinking Water Quality" as the legally binding standards for regulated drinking water supplies. Within the Guidelines, the Maximum Acceptable Concentration for lead is 10 μg/L and is intended to apply to average concentrations consumed for extended periods

(Health Canada, 1992). The guidelines also suggest that people flush taps before consuming water, and therefore tests also be conducted on flushed samples. The Guidelines do not offer a clear monitoring method, and the results of the testing may underestimate actual exposure conditions due to the recommendation of flushing. Consequently, Health Canada (2009) developed a guidance document, "Guidance on Controlling Corrosion in Drinking Water Distribution Systems", to assist water suppliers in developing corrosion control and monitoring programs. The guidance provides testing protocol and corrective measures for two exposure patterns: in residential settings and non-residential settings.

The residential protocol outlined in the Guidance is much like the LCR testing: first draw samples of 1 L are collected following a minimum of six hours stagnation; it is based on a 90th percentile lead action level of 15 μg/L with the purposes of assessing the overall behaviour of the system; the number of sites sampled in a monitoring round are dependent on the population served by the water supplier, shown in Table 3.1; and a minimum of 50% of the sites tested must have a lead service line in systems where they are present (Health Canada, 2009). Priority is also directed to sampling of sites with lead pipes or copper pipes with lead soldered joints, and at sites which have leaded brass components. Second tier testing of four consecutive one litre samples is described if the 90th percentile concentration exceeds the action level, in order to determine the major sources of lead which should help the utility optimize their corrosion control and provide accurate information to the public. An optional 30 minute stagnation testing method for residential testing is also provided and is recommended for sites with lead service lines in jurisdictions where a six hour stagnation time is not practical or regulatory obligations restrict the use of the two tier approach (Health Canada, 2009). This method involves collection of the first four consecutive one litre samples, and the action level is exceeded when the average lead in the four samples is greater than 10 μg/L at more than 10% of the sites. The 30 minute stagnation time is useful in jurisdictions where sampling is required to be conducted by an employee of the utility, such as in Ontario (Government of Ontario, 2007); however, the time will be insufficient to provide a perspective of worst case lead levels. One criticism of the first draw option of testing is that this method may also miss the worst case lead levels in sites with lead service lines, despite the long stagnation times greater than six hours. This is because the highest lead concentrations are expected to be found in water which stagnated in the lead service pipe, and the best means for determining the contribution from stagnating in the service pipe would include collection of the third to sixth litre (Health Canada, 2009).

Table 3.1: Number of sample sites required based on population served by (Health Canada, 2009; USEPA, 2008)

Size Category	System Size	Number of Samples	
		Initial Monitoring	Reduced Monitoring
Large	> 100,000	100	50
	50,001 – 100,000	60	30
Medium	10,001 – 50,000	60	30
	3,301 – 10,000	40	20
Small	501 – 3,300	20	10
	101 – 500	10	5
	≤ 100	5	5

Exceedences in the residential testing protocol require corrective actions by the water supplier, including the implementation of public education programs, initiating water treatment changes to reduce the corrosivity of the water towards lead, and replacing lead service lines (Health Canada, 2009).

One of the major differences between the Health Canada Guidance (2009) and the LCR (1991) is that the LCR is a regulation and that Health Canada's document provides guidance, and any protocols or objectives presented are merely recommendations. The LCR presents a timeline with mandatory testing milestones, including initial testing which requires water supplies to conduct at least two consecutive six month rounds of monitoring before a water supplier could begin reduced annual sampling (USEPA, 2010). On the other hand, Health Canada (2009) places far less emphasis and is not completely clear on the issue of testing in sequential seasons. Testing of consecutive seasons is mentioned in the Guidance (2009), but this is only indicated as a concept for follow up monitoring after implementation of corrosion control and its optimization; however, according to the Guidance, this is only required if the action level is exceeded in the initial monitoring event. In the event that a Canadian water supplier does not exceed the action level in their first round of monitoring, it is conceivable that they would deem their corrosion control sufficient and would proceed with annual monitoring. Directly proceeding to annual monitoring would cause a utility to overlook seasonal variations, which could mean that the period where lead elevations are greatest may not be tested, and worst case exposure would be neglected.

Health Canada (2009) and the USEPA (2010) suggest reduced annual monitoring be conducted in the summer as they presume that the highest lead levels are expected to occur during this season; however, summer lead concentrations are not guaranteed to be highest, as temperature effects on lead release are complex (Schock et al, 1996; Schock, 1990). While warmer waters are likely to increase corrosion reaction rates, solubility of the various corrosion by-products may either increase or decrease with increasing water temperatures (Schock, 1990). A guide for lead monitoring in European countries suggests that lead dissolution will be twice the concentration in the summer compared to the winter, and therefore requires sampling in consecutive six month periods to include testing while water is at both the warmest and the coolest temperatures (Hoekstra et al, 2009). Conversely, a study examining lead data from more than 350 US utilities found that warm water conditions did not result in elevated lead compared to the cold water conditions (Dodrill et al, 1995).

The direct effect of temperature on lead solubility is not the only factor which could cause seasonal trends in lead levels. Seasonal variations in performance at the water treatment plant could also have an effect on lead release. As an example, coagulant performance is affected by temperature (Droste, 1997). Poor coagulation performance resulting in increased levels of natural organic matter (NOM) could potentially result in elevated lead release (Korshin et al, 2000). Fluctuations in coagulant metal residual concentrations could also impact lead release. Correlations between particulate lead and particulate iron, and particulate lead and particulate aluminum have been documented, suggesting adsorption of lead to particulate iron or particulate aluminum as a possible mechanism for lead release (Knowles, 2011; Deshommes et al, 2010). Consequently, plant residual concentrations could potentially cause a subsequent increase in lead concentrations.

Health Canada's non-residential protocol has many similarities to the guidance testing developed under the LCCA by the USEPA (2006) for schools. One of the major differences between the residential and non-residential testing is that with the non-residential testing, the action level is assessed on a site-by-site basis, and if there is an exceedence, informing the users of the outlet and the implementation of corrective measures are the duties of the building owners (Health Canada, 2009). The objective of the non-residential testing is to identify and resolve specific lead issues at drinking water outlets within a building, such as an office building, a school, and a day care centre. As it is intended to identify specific outlets which are sources of lead, sample volumes of 250 mL are intentionally small and the action level lead concentration is therefore slightly higher than the MAC at 20 μg/L, because the sample is expected to be far less diluted than with a 1-L sample. Priority is directed at sites which are used for the purposes of drinking, and if there is an exceedence, corrective measures should be carried out. These may include: education of the occupants of the building about the lead issue; follow-up tests to determine whether the outlet or the upstream plumbing is the source of lead; regular flushing of the outlet; or removal and possible replacement of the outlet or upstream components.

Although it is typically not a requirement for a utility to conduct non-residential testing, it is useful for a utility to understand the extent of lead issues in large buildings within its system. Non-residential drinking water is a significant source of lead exposure, and monitoring for lead in drinking water in non-residential buildings is therefore critical (Barn and Kosatsky, 2011). Indeed, some provinces, such as Ontario, include the testing of non-residential buildings such as schools within their regulations for lead monitoring (Government of Ontario, 2010a). Long plumbing networks, long stagnation periods, infrequent usage patterns, and large amount of leaded components may result in elevated lead concentrations in non-residential buildings; even in systems where corrosion control has been deemed sufficient by residential monitoring (USEPA, 2006). High variability of lead levels between outlets suggests that the only way to be certain that all sources of lead are discovered and removed is to sample at all outlets (Maas et al, 1994). Resources are typically limited, so testing of all individual sites is not always feasible. Development of a database of information to determine the variables associated with high risk sites is useful to optimize the ability of a monitoring program to discover sites with elevated lead. While the USEPA (2006) provides guidance for sampling in non-residential buildings, protocols should be developed to provide building owners assistance in determining their sites with the greatest risk of having elevated lead levels. The potential sources of lead in a non-residential building are illustrated in Figure 3.1, and include solders, pipes, outlets such as fountains, and inline brass devices.

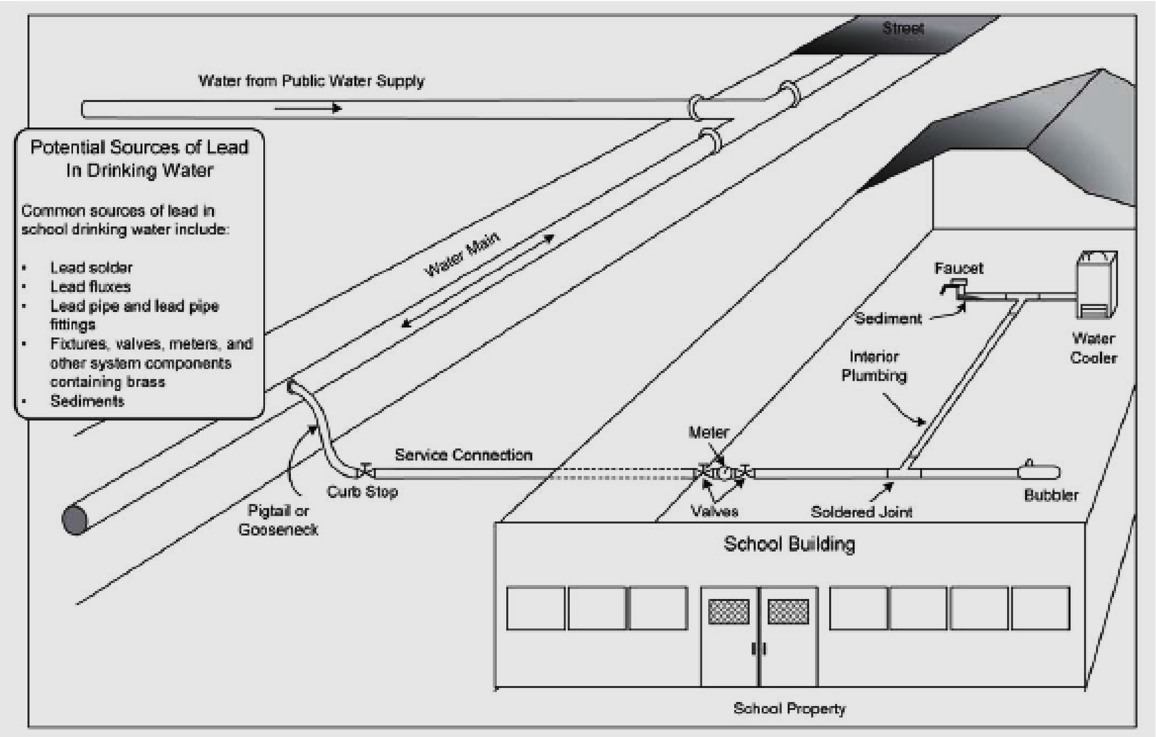

Figure 3.1: Sources of lead in a non-residential building (USEPA, 2006)

Shortfalls of a water supplier's corrosion control program, which may not be observed through the residential testing, may be identified through non-residential monitoring. The worst case scenario created by long plumbing networks and irregular usage could identify need for corrosion control optimization that is not recognized through the limited sampling required in the residential program. Collection of non-residential data may also be vital for a utility in the event that an owner of a non-residential building finds elevated lead in their water. The utility may use their non-residential data to demonstrate the high within-building variability and the importance of individual outlets as lead sources. The water supplier may develop a database of fountain and faucet models which release high lead, and share this information with customers to prioritize their sampling sites based on likelihood of elevated lead, to help building owners improve the effectiveness of a sampling program (Barn and Kosatsky, 2011).

The objective of this study was to conduct several rounds of lead monitoring for drinking water supplied by the JDKWSP, in both residential buildings and non-residential buildings, using the Health Canada (2009) testing protocols. The monitoring rounds were collected during consecutive seasons, in order to detect seasonal variation, and multiple rounds were performed to support any findings. The objectives of this research were: to determine the relative corrosivity of the water supplied by JDKWSP through residential testing; to identify specific circumstances which may result in elevated lead in both residential and non-residential settings; and to develop a catalogue of outlets which have a propensity to release elevated lead in non-residential settings.

3.2 Materials and Methods

Description of Setup. All tests for this thesis were conducted using tap water treated at the JDKWSP. The JDKWSP pumps water from Lake Pockwock, which lies in a pristine watershed protected by provincial designation and regulations. The source water is slightly acidic lake with a typical pH of roughly 5; it has low alkalinity, measuring less than 1 mg/L as $CaCO_3$; and is of high clarity, with typical turbidity of roughly 0.3 NTU. A summary of the raw and treated water characteristics for the JDKWSP is provided in Table 3.2.

Table 3.2: Typical water quality data of raw and treated water at JDKWSP

Parameter	Raw Water	Treated Water	Guideline MAC	Guideline AO
pH	5.0	7.4		6.5 – 8.5
Turbidity (NTU)	0.3	<0.1	0.2/1.0*	
Alkalinity (mg/L as $CaCO_3$)	< 1.0	20.5	-	-
Hardness (mg/L as $CaCO_3$)	4.0	14	-	-
Chloride (mg/L)	6.0	9.5		≤250
Sulfate (mg/L)	4.0	8.5		≤500
Copper (mg/L)	0.079	0.03		≤1.0
Lead (μg/L)	< 0.5	< 0.5	10.0	
Zinc (mg/L)	0.01	0.103		≤5.0
Iron (mg/L)	< 0.066	< 0.020		
TOC (mg/L)	2.5	1.8	-	-

*Must be below 0.2 NTU 95 percent of time

Halifax Water employs a sophisticated corrosion control and monitoring program which includes: an annual residential monitoring program, which is conducted according to the Health Canada residential testing program; quarterly analysis of lead, copper, and steel coupons located throughout the distribution system; weekly analysis of distribution system water quality at selected sites; a lead service line replacement and education program; and dosing a zinc ortho/polyphosphate blended corrosion inhibitor at the treatment plant.

Experimental Methods. Three rounds of testing were conducted following the two protocols described in the Health Canada (2009) guidance for residential and non-residential buildings. In each of the three rounds, roughly 30 residential buildings and approximately 100 sites in 48 non-residential buildings were sampled. Sampling was conducted during October 2010, October 2011, and February 2012 for the residential buildings; and during February 2011, October 2011, and February 2012 for the non-residential sampling. The preferred sites for this investigation were outlets which were used primarily for consumption purposes which included kitchenettes and fountains when they were available. Every building throughout Dalhousie University was tested, so in many cases, the only outlets available for testing in many buildings were from bathroom faucets.

Figure 3.2: Sample images of sites visited during the residential and non-residential testing

Residential Testing:

Residential testing was conducted at 34 sites in total, which included three typical service pipe configurations: lead pipe on both the public and private side; copper pipe on public and private side; and copper pipe on the public side connected to lead pipe on private side. Of the 34 sites, six had partially replaced service pipes, three had full length lead pipe, 18 had full length copper tube, and the remainder had either unknown service pipe materials or an uncommon configuration. Samples were collected between 6 – 8 am following overnight stagnation of roughly 12 hours. First draw one litre samples were collected according to the "Tier 1" stage of the protocol. The one litre sample was shaken vigorously before being poured into a smaller 250 mL bottle which was kept chilled until transportation to the lab for metals analysis. The remaining volume of the one litre sample was tested for pH, temperature, free chlorine residual, and turbidity. While these measurements were conducted, the water was allowed to flush for roughly five minutes, before the second sample, representing the flush sample. Measurements for pH, temperature, free chlorine residual, and turbidity were also conducted on the flush sample in the two later rounds as well. Faucet manufacturers were recorded, and the water meter was inspected to ensure the service line material from the utility records were accurate.

Non-residential Testing:

Testing was conducted primarily at sites which were used for the purposes of drinking or cooking and were selected to represent different locations on different floors within all of the buildings at the institution. In the three rounds of sampling, tests were conducted at roughly 100 sites in 48 buildings. Faucets and fountains were covered the day prior to testing in order to allow water to stagnate for eight to 16 hours before testing. Following the stagnation period, first draw samples of 250 mL were collected, chilled, and delivered to the laboratory each day. Following the first draw sample, on-site measurements for pH, temperature, free chlorine residual, and turbidity were obtained. The faucet or fountain brands were also recorded.

Analytical Methods. Samples were collected in polypropylene bottles, which were washed using phosphate free detergent wash, rinsed in a 10% v/v nitric acid bath, and then rinsed with ultra-pure water, and air dried.

Samples were prepared using the USEPA Method 200.8, where samples were acidified to pH below 2 adding concentrated nitric acid directly into sample bottles for a minimum of 16 hours. In a parallel study, results from acid digested samples were compared with results from further heat digestions to determine the necessity of heated digestions. Samples which had already undergone USEPA 200.8 digestion were further digested by adding 0.5 mL of concentrated HNO_3 to 10 mL of sample and heated at 105°C for a minimum of 2 hours, in accordance to Standard Method 3030E. Concentrations between the two preparation methods did not vary significantly, and paired t-tests demonstrated that the difference between the two methods was not statistically significant (99% confidence).

Metals were analysed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) using a Thermo Fisher X Series 2 ICP-MS using Standard Method 3125, with detectable limits of 0.4 μg/L, 0.7 μg/L, 0.6 μg/L, 7 μg/L, and 0.6 μg/L for lead, copper, zinc, iron, and tin respectively. Temperature and pH were both measured using an Orion pH probe, which was calibrated daily using standards of pH 4 and pH 10. Turbidity was measured using a Hach 2100P portable turbidimeter, and free chlorine was measured using a Hach pocket colorimeter by the DBP method. During the preliminary sample round, alkalinity was measured by Standard Method 2320B.

Statistical and Data Analysis. The critical number for the residential testing, according to both the LCR testing and the Health Canada Guidance Residential Testing (USEPA, 2007; Health Canada, 2009), is the 90th percentile lead concentration, which is used to assess the overall corrosive behaviour of the distribution system. This value is determined from each round of monitoring by ordering the results in increasing order, ranking the lowest concentration as '1', and the highest concentration as the rank equal to the amount of samples obtained. The 90th percentile concentration is the concentration with the rank equal to the total amount of samples, multiplied by 0.9. When the total number of samples multiplied by 0.9 does not equal an integer, the 90th percentile is interpolated.

3.3 Results and Discussion

Residential Testing:

Three rounds of testing were conducted at all single storey and multiple storey residential buildings located throughout the academic institution's campus. In each of the three rounds, 31 sites were visited, and there were an additional three others which were tested either once or twice. Of the sites with the reduced monitoring, one was tested only twice because it was originally tested under the non-residential testing at an unsuitable testing location (bathtub in building D7); another was removed from the monitoring program as it was from a sink which was never used for consumption; and the third site was only tested once because it was closed for construction during second and third monitoring rounds.

Monitoring rounds were conducted in the fall of 2010, the fall of 2011, and the winter of 2012 and the results are summarized in Table 3.3.

Table 3.3: Summary of residential results through three rounds of monitoring

	October 2010	October 2011	February 2012
Number of sites tested	33	32	32
90th Percentile (µg/L)	7.9	5.2	22.6
Average Lead (µg/L)	4.6	2.6	6.8
Maximum Lead (µg/L)	31.3	16.2	41.1
Number of Sites above MAC	3	3	4

Based on the Health Canada Guidance testing protocols, the corrosion control implemented by Halifax Water was shown to be effective through the first and second round of monitoring, with 90th percentile lead concentrations well below the action level of 15 µg/L, at 7.9 and 5.4 µg/L, respectively (Health Canada, 2009). However, the third round, which was conducted in the winter, had greater lead concentrations at the majority of the sites, with particularly large spikes at sites which showed elevated lead in the first two rounds. This resulted in a 90th percentile lead concentration of 22.6 µg/L, which exceeded the action level, suggesting further work to optimize the corrosion control implemented by Halifax Water should be undertaken. Greater lead levels in the winter compared to summer rounds was considered unusual; especially given that monitoring programs such as the Health Canada Guidance and the LCR both recommend conducting annual sampling during the summer to account for the worst case scenario (Health Canada, 2009; USEPA, 2005).

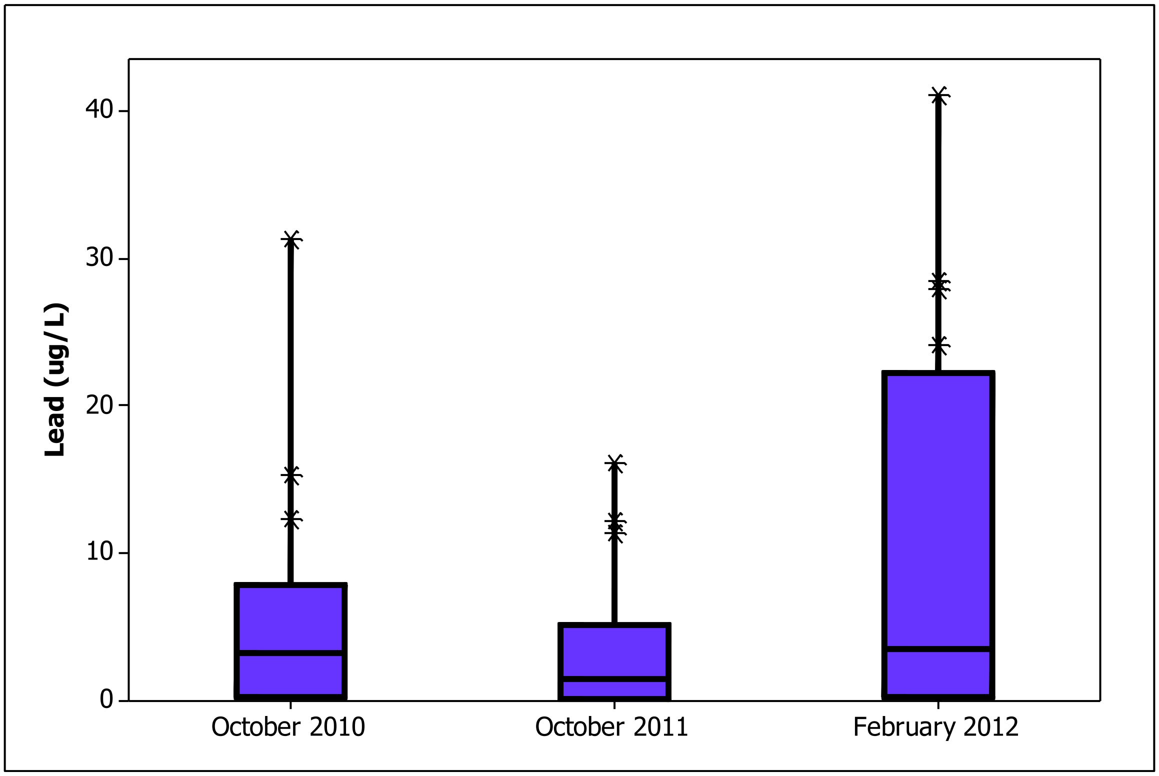

Figure 3.3: Boxplots of lead concentrations through three rounds of residential monitoring, boxes show 10- 90th percentile concentrations.

The utility should consider increasing annual monitoring to semi-annual monitoring periods, until compliance with the action level is met throughout monitoring programs in consecutive six-month periods. One limitation of this study is that a lead monitoring program initiated by a utility serving a population the size of Halifax would require testing in at least 100 sites during annual monitoring, and 50 sites under a reduced annual monitoring program, as shown in Table 3.1 (Health Canada, 2009). This is compared with roughly 30 sites which were sampled in this study. With a greater amount of test sites, the 90th percentile concentration may not have jumped so dramatically in the third round when one site in particular dramatically increased. Although, this seasonal trend was also evident in all the other testing in this research, including the non-residential testing and the follow-up fountain study. The differences in first draw lead concentrations from the fall testing compared to the winter testing were found to be statistically significant by paired t-testing at the 95% confidence level. Both USEPA (2007) and Health Canada (2009) suggest conducting annual monitoring during the summer, as it is expected that warmer water conditions will result in greater lead release; however, a survey of 365 US utilities found that the warm water conditions did not result in higher lead release. In fact, the opposite effect was found in the lowest alkalinity category of less than 30 mg/L as $CaCO_3$ (Dodrill et al, 1995).

The seasonal lead fluctuations measured in this study have been attributed to seasonal coagulation and flocculation performance. The coagulation and flocculation process is highly dependent on water temperatures (AWWA, 2011). A coagulant's pH of minimum solubility, which is the pH where the maximum amount of solid floc forms, is dependent on temperature. In colder climates where water temperatures can vary, adjustments to pH are important to maintain optimal dosing. It was therefore possible that in the winter, the plant was not operating at the optimum pH for coagulation. Temperature also affects the flocculation process. In some cases, utilities are designed for seasonal adjustments to flocculation intensity for best conditions for the changes in water quality (AWWA, 2011); on the other hand, the JDKWSP uses hydraulic flocculation, and therefore cannot adapt to any seasonal changes. Poor flocculation during the winter could therefore be considered as a source of the DOC and aluminum fluctuations.

The fluctuations in aluminum residual concentrations of the finished water exiting the supply plant were considered the most likely cause for the seasonal fluctuations in lead levels. Elevated aluminum residuals likely led to the adsorption of lead to aluminum oxides, resulting in elevated lead concentrations, as concluded in a study of residual coagulant metals on lead release (Knowles, 2011). Plant data of aluminum residuals was examined for the period of this research, and is provided in Figure 3.4. Throughout the year, the plant residuals remained below the provincially regulated MAC of 0.2 mg/L total aluminum for a direct filtration treatment plant, but the winter concentrations, which were substantially higher than the summer levels, approached this threshold (Nova Scotia Environment and Labour, 2007).

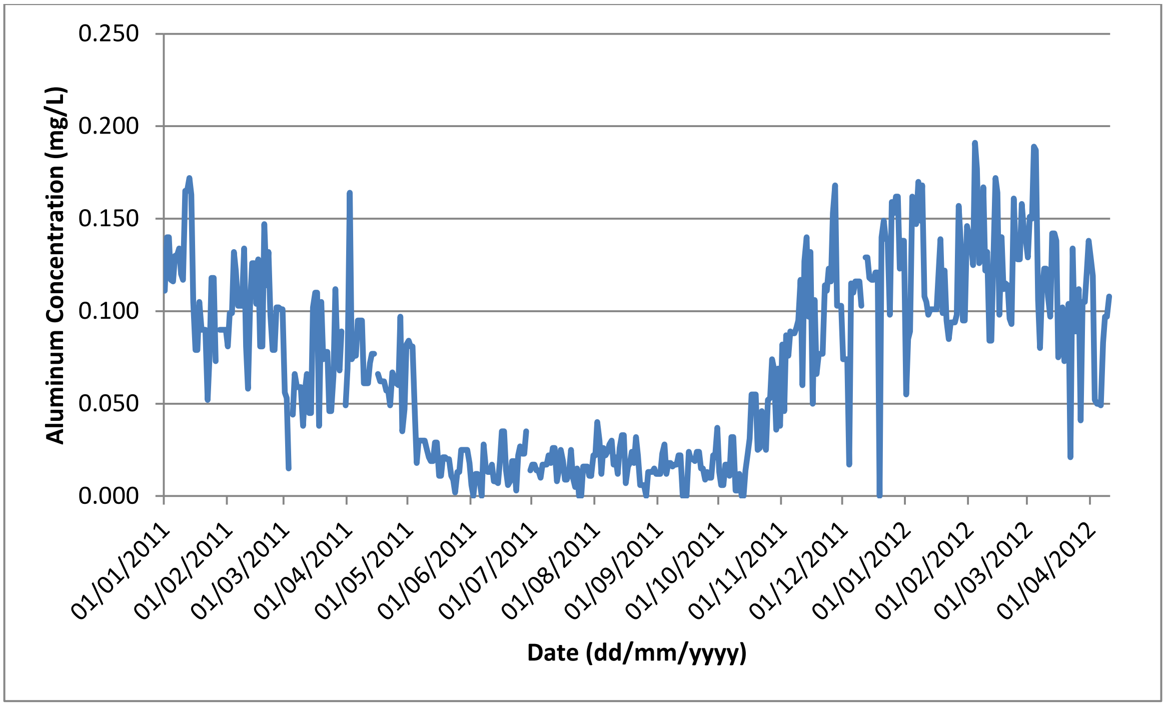

Figure 3.4: Plant data of aluminum residual concentrations

The seasonal effect on coagulation/flocculation performance leading to the fluctuation of aluminum residuals may also have impacted NOM removal at the treatment plant, consequently causing elevated lead levels in the winter sampling periods. NOM levels, as measured by TOC, were relatively stable throughout monitoring (shown in appendix C), with monthly average concentrations in the range of 1.7 – 2.2 mg/L; however, the difference between the average concentration of the samples collected during the summer of 2011 (August and September) was statistically different from the average concentration of the samples collected during the winter months of 2012 (March, April, May).

In a bench-scale study examining the effect of coagulation residuals on lead release using the same source water, TOC and DOC were not found to correlate with lead release (Knowles, 2011); however, it should be noted that in that study, the correlation between lead release and TOC/DOC was tested for between treatments of various coagulants, and not in fact between changing TOC/DOC levels resulting from treatment of a single coagulant. Additionally, under the treatment condition which mimicked that of JDKWSP, the aluminum residuals were as high as 1 mg/L, which likely would have masked any lead release which would have resulted from NOM.

Other examples in the literature have demonstrated that increases in soluble lead levels resulting from increased DOC are especially notable between concentrations ranging from 0 – 3.5 mg/L (Korshin et al, 2005). In a similar study of lead release from brass, it was found that increases in NOM increased lead release from brass, particularly in increases of DOC in the range of 0 – 2.0 mg/L (Korshin et al, 2000). Although the changes in TOC observed throughout this study were seemingly trivial, further research should be considered to determine if there is an annual trend in DOC levels in the distribution system; and if so, whether the fluctuations are in fact great enough to cause the seasonal lead trends observed in this research.

Various other causes of the seasonal effect were considered in this study but were either disproved or determined to be unlikely. Fluctuations in the efficiency of the corrosion inhibitor was an unlikely explanation, because previous research on corrosion inhibitors for the same source water found temperature did not have a significant effect on lead release (Woszczynski, 2011). Higher demand during the summer, resulting in more consistent water quality, may have allowed the development of more uniform protective scales; however, this theory would require further research to support or disprove. Another theory investigated was the possibility of warmer water stagnating in the premise plumbing during the winter because of the use of building heating and cooling systems; however, temperature data from residential buildings showed that first draw temperatures were still warmer in the summer compared to the winter. First draw temperature measurements were recorded at numerous sites in both the October 2011 and February 2012 sampling rounds, and the water temperature was in fact higher during the fall round, with a difference which was statistically significant based on paired t-testing at the 95% confidence level.

First draw lead results from the three rounds of residential testing are illustrated in Figure 3.5. Buildings are labelled based on service pipe material: ‘A’ buildings all have partially replaced service pipes, with copper connected to lead; ‘B’ buildings have full length lead service pipes; ‘C’ buildings containing full length copper services; and ‘D’ buildings were unknown or had less common materials and configurations.

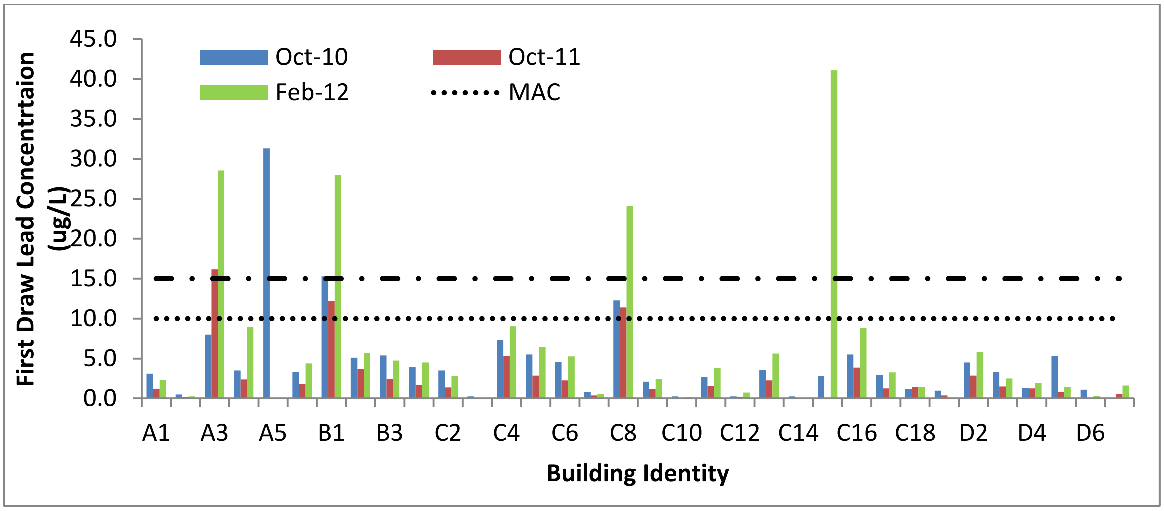

Figure 3.5: Residential testing first draw lead concentrations through three rounds of monitoring

A large proportion of the sites with elevated lead concentrations were found at sites with lead service lines, especially when consideration was given to the fact that there was a lower proportion of sites which contained lead pipes. Average concentrations in each sample round were higher at sites with lead services (full or partial) compared to sites with full length copper services, but this difference was not statistically significant at 90% confidence, as shown in Figure 3.6.

Sites with copper services were not immune to elevated first-draw lead concentrations. This was especially notable in the third round, when an equal number of sites with copper services exceeded the MAC as sites with lead services, demonstrating the significance of either soldered joints or brass fixtures as lead sources. The lack of difference between the average lead levels from sites with or without lead services can also be interpreted in two ways. One could suggest that this means that the JDKWSP employs successful corrosion control treatment, particularly in the summer; conversely, it could be perceived that this is simply an ineffective testing protocol and that worst-case conditions were likely missed in first draw samples from sites with lead services.

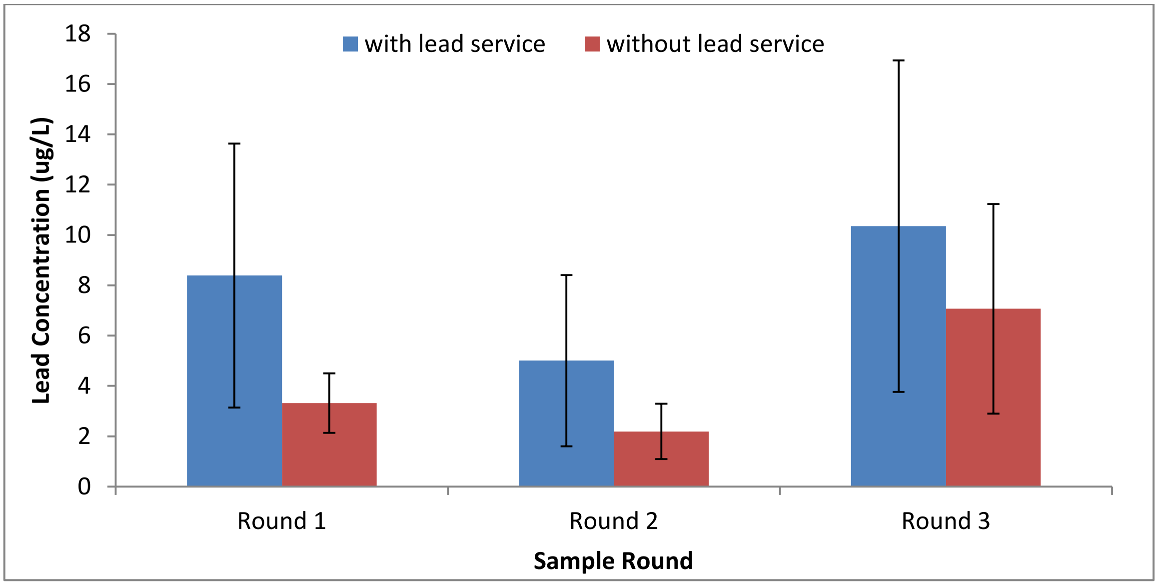

Figure 3.6: Residential testing average first draw lead concentrations from sites with and without lead services

The winter spikes were typically most significant at sites which already experienced elevated lead during the fall monitoring; however, site C15 had low levels in the first two rounds but experienced a major spike in the lead concentration in the winter. The spike resulted from a switch in testing location which was done to test at a kitchenette faucet which was not discovered until the final round. Changing sites is not recommended during the initial stages of a lead monitoring program, but it was done in this study to determine the actual exposure to lead in that building (USEPA, 2010). The significant difference in lead levels at the two sites in C15 demonstrates the within-building variability of lead levels, and the importance of properly selecting the testing sites, both to locate the high exposure sites, as well as the sites which are used for consumption.

Flushing of faucets for several minutes significantly reduced lead levels measured at the tap at the 95% confidence level. Results from the flushed samples in the three rounds of lead monitoring are illustrated in Figure 3.7. Flushing was particularly effective in sites with non-lead service lines. At several sites with lead services, including A3 and B1, high lead concentrations were maintained through flush samples, which suggests that elevated lead may be present in the water throughout the day.

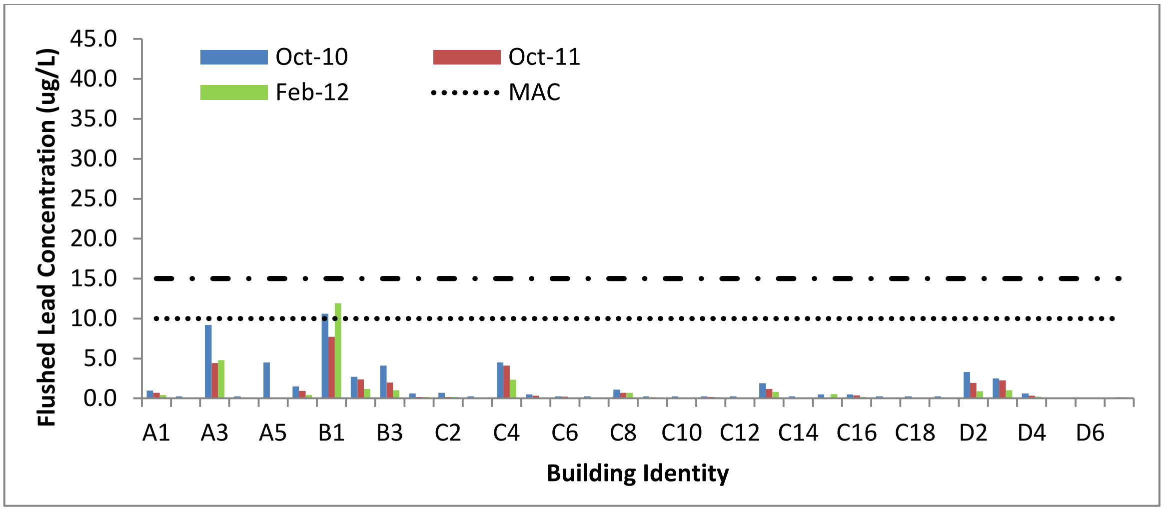

Figure 3.7: Residential testing flush lead concentrations through three rounds of monitoring

Table 3.4: Comparison of filtered results with the unfiltered results from the lead monitoring programme

Building	Lead (µg/L)				
	Unfiltered			Filtered	
	Oct-10	Oct-11	Feb-12	Feb-11	Feb-12
A3	8.0	16.2	28.6	< 0.5	
A5	31.3			< 0.5	
A6	3.3	1.762	4.367		< 0.4
B1	15.3	12.2	28.0	< 0.5	
C6	4.6	2.3	5.3		< 0.4
C8	12.3	11.4	24.1	< 0.5	

Lead filters (NSF 53 certified) were installed at all sites that were sources of a sample with a lead concentration greater than 10 µg/L. At the four sites above the MAC in the first round, filters were tested shortly after their installation following the same overnight stagnation and testing protocols used for the monitoring program. Lead concentrations were non-detectable in all samples collected at this time, as shown in Table 3.4. Two of these sites were tested once more in the third round of monitoring and lead levels were still below detection levels of 0.4 µg/L. The reason sites A6 and C6 had lead filters installed was because they were both connected to building A5. These sites were actually used for drinking purposes; whereas A5 was located in a custodial closet which was not a source of water for consumption, so this site was not tested again throughout the study.

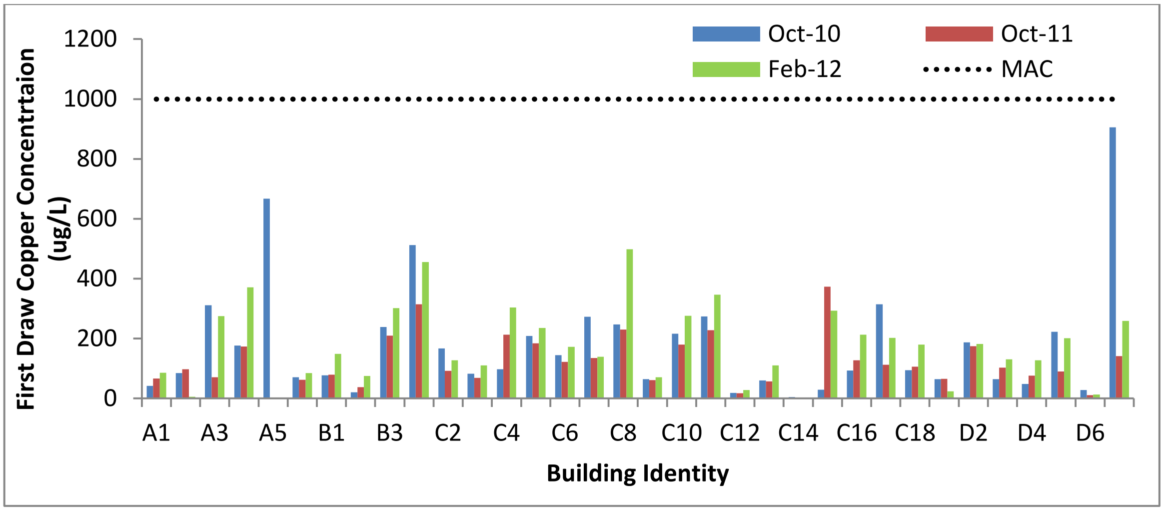

Figure 3.8: Residential testing first draw copper concentrations

Residential copper concentrations, shown in Figure 3.8 typically ranged from 20 μg/L to 300 μg/L, and there was not a single exceedence of the MAC of 1 mg/L. Copper concentrations were relatively stable through the three rounds of testing, with no observable seasonal trend, and the difference between the fall 2010 and the winter of 2012 was not statistically significant based on paired t-testing at the 95% confidence level. The box plot in Figure 3.9 illustrates the consistency of the dispersion of copper concentrations through the three rounds. The boxes indicate the 10th to the 90th percentile concentrations, and cover a similar range of data through the three rounds, particularly the October 2010 and February 2012 rounds.

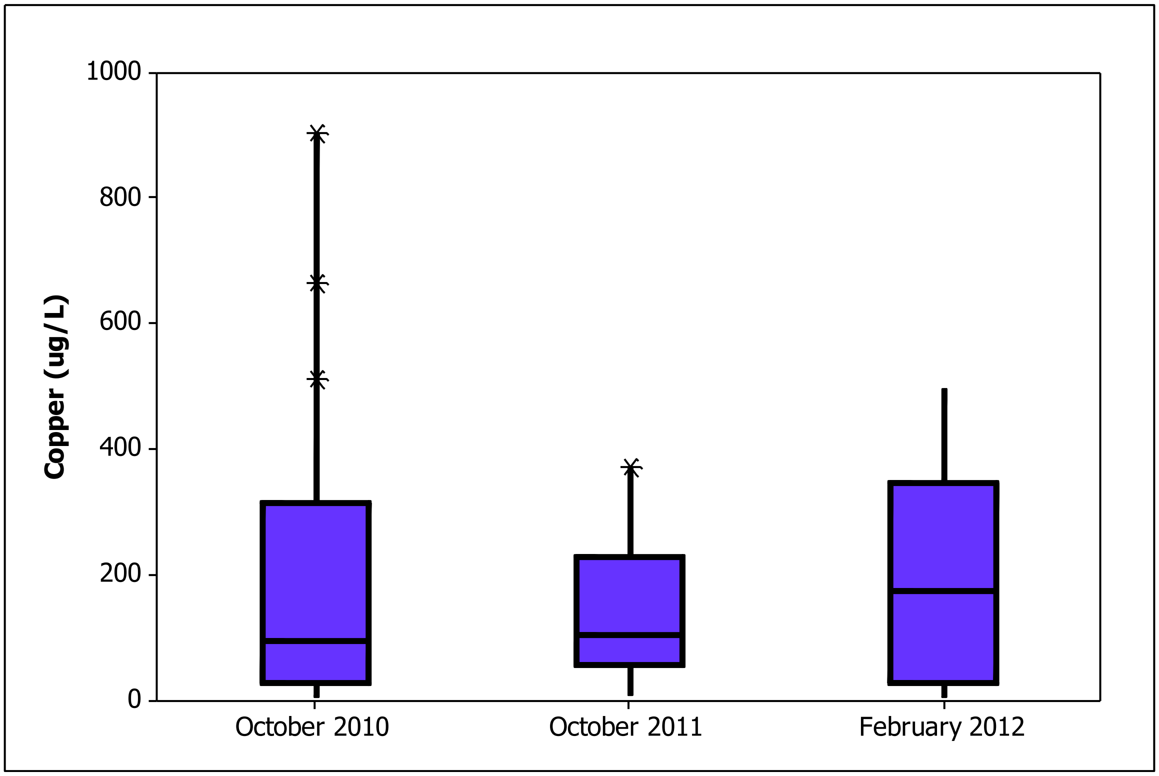

Figure 3.9: Box plots of residential copper concentrations through the three rounds of testing

Non-Residential Testing:

Three rounds of non-residential monitoring were conducted in February 2011, October 2011, and February 2012, with samples collected at 102, 104, and 97 sites respectively. Through each of the three rounds of non-residential testing, the majority of the sites had 250 mL first draw lead concentrations below 10 µg/L, and the number of AL exceedences was low, with only five in the February 2011 round, three in the October 2011 round, and five in the February 2012 round. Indeed, the only round to have an AL exceedence rate as high as 5% was the third and final round in February 2012. The distribution of the lead concentrations is presented in Figure 3.10, which shows the majority of the sites produced low lead levels. The same seasonal variation exhibited in the residential testing was found in the non-residential testing. Concentrations tended to be higher in February 2011 and February 2012 compared to October 2011. Paired t-testing confirmed the difference was statistically significant at the 95% confidence level. The seasonal variation is also shown in the box plot, Figure 3.11, where the box illustrating the 10th to 90th percentile concentrations is dispersed over a higher range in the two rounds conducted in February of 2011 and 2012, compared to the round conducted in October 2011.

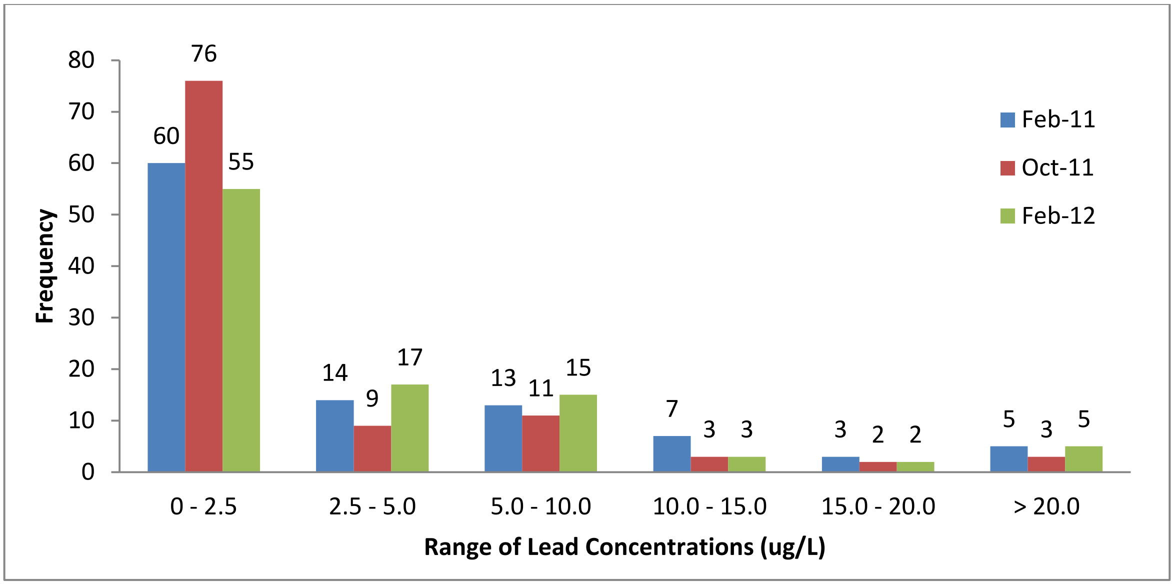

Figure 3.10: Distribution of lead concentrations found in three rounds of non-residential sampling

The non-residential sampling produced some of the highest lead concentrations in all the testing of the lead monitoring program. Lead concentrations as high as 50 µg/L were found in the October 2011 round, when residential testing determined the water to not be particularly corrosive and deemed the corrosion control implemented by Halifax Water as effective (Health Canada, 2009). Sources of lead in non-residential buildings include lead solders and brass devices. Lead services are typically not found in these buildings, because the large diameter for the services in these buildings makes lead unsuitable. The elevated lead levels therefore result from intermittent flow patterns; long networks with numerous joints which may be leaded in older buildings; long periods of stagnation; brass devices such as valves, meters, and faucets; and drinking fountains which contain leaded components (USEPA, 2006).

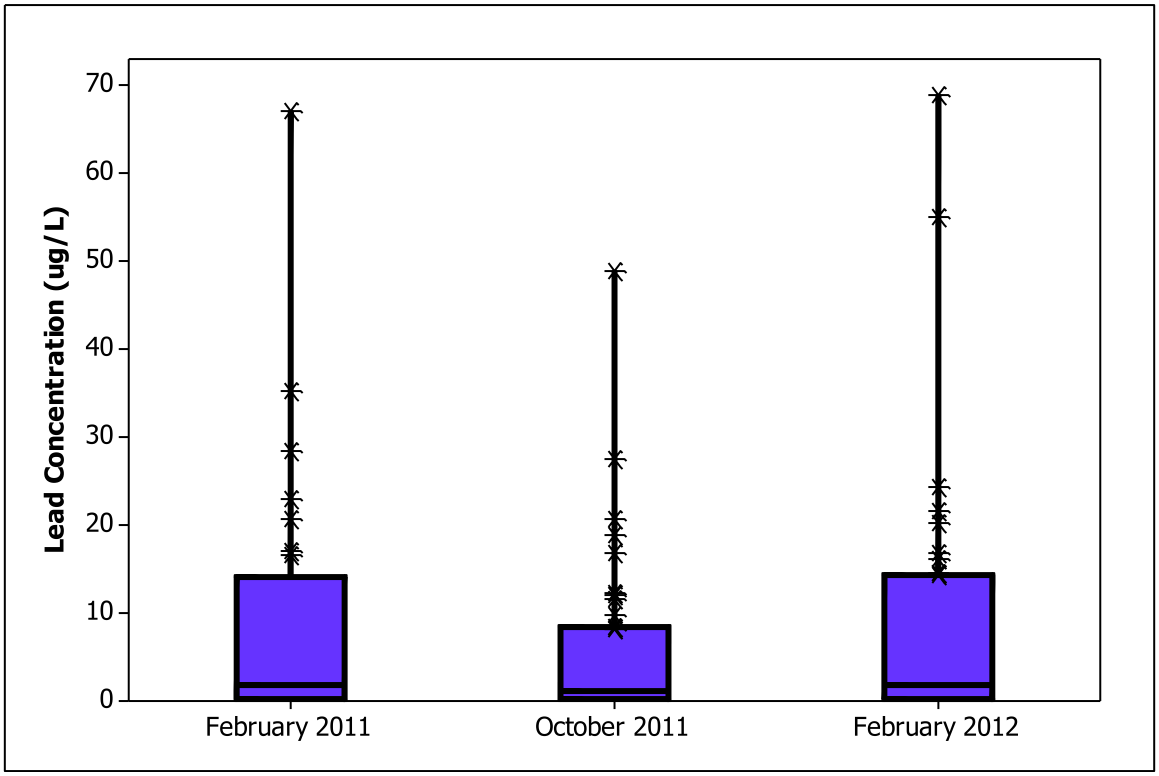

Figure 3.11: Box plots of lead concentrations from the three rounds of non-residential monitoring

The highest lead concentrations were typically found at the same sites throughout each of the three rounds. In the first, second and third round of sampling, there were 15, 8, and 10 sites that exceeded 10 µg/L; however, through the three rounds there was only a total of 17 sites to exceed this value. First draw lead concentrations from these sites are presented in Figure 3.12. Sites with low lead were consistently sources with low lead levels.

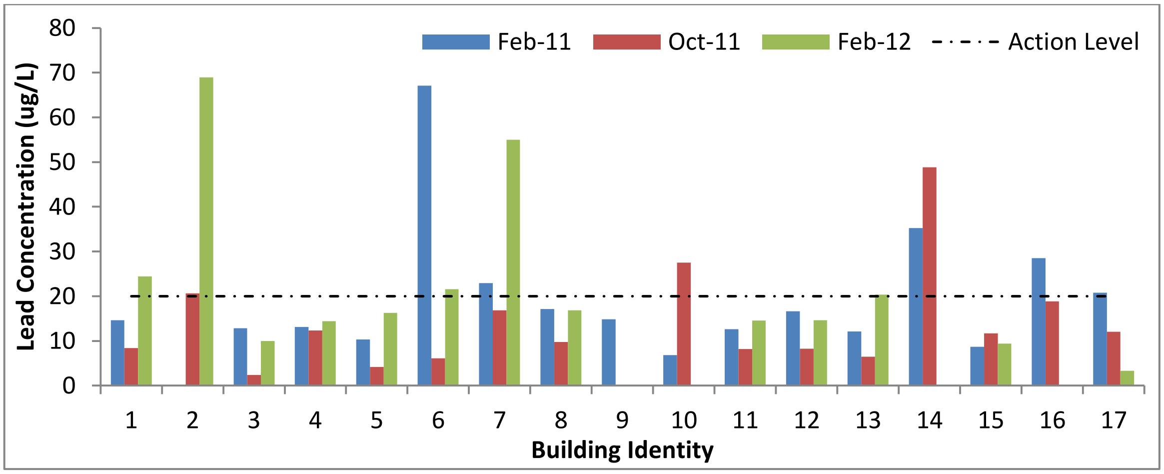

Figure 3.12: Lead concentrations at any of the sites which produced water above 10 µg/L in any round of sampling

Sites with elevated lead were isolated and localized. Of the five AL exceedences in the first round of non-residential sampling, three were from samples drawn from drinking water fountains located in buildings where at least one other outlet was tested to have lead levels below 5 µg/L. This suggests that the elevated lead concentrations were not because of particularly corrosive water, and that it was not likely a problem with the building piping, but instead a problem with the outlet.

Figure 3.13 presents boxplots of lead concentrations from samples collected during the non-residential monitoring, and compares lead levels which were obtained from sites with fountains and faucets. Sites with faucets above the action level were found either in kitchenettes which were evidently rarely used, or from bathroom faucets where regular use would be for washing hands and not for purposes of consumption. These sites are highlighted in Figure 3.13, where the outlier lead concentrations from bathroom faucets where risk of exposure would be low are highlighted in blue, and the sites in residence kitchenettes which appeared to experience very infrequent use are highlighted in green.

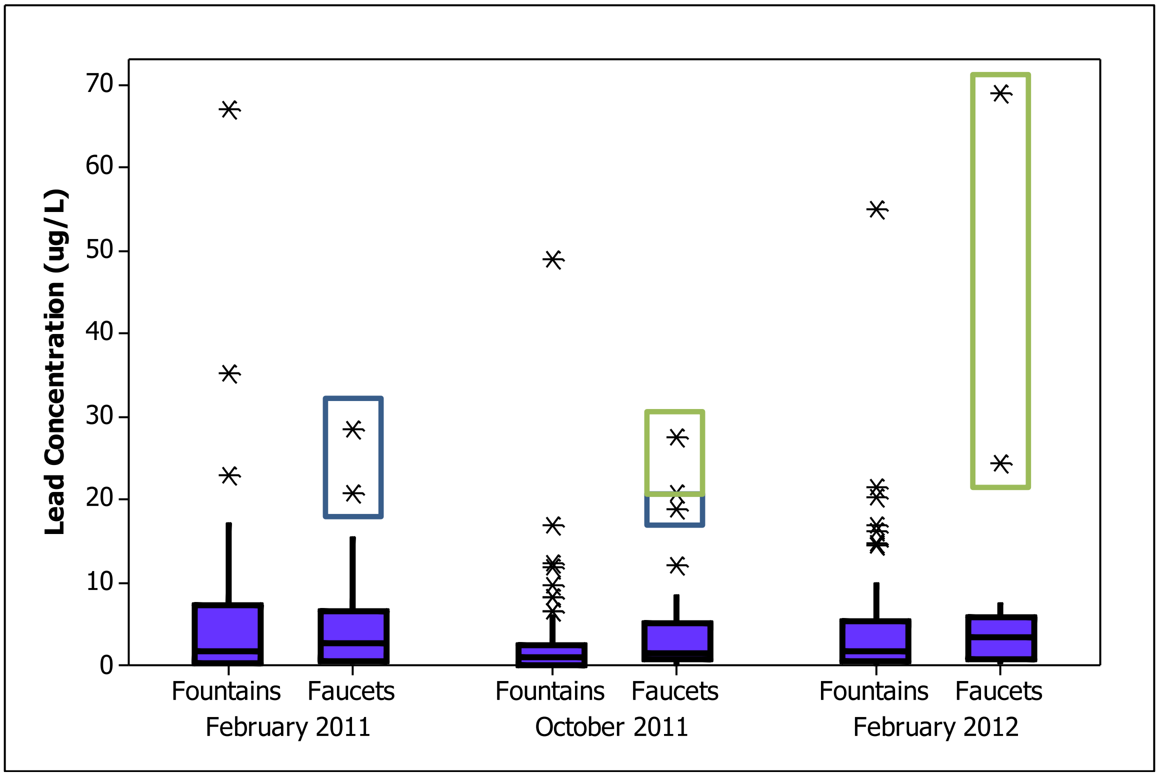

Figure 3.13: Comparison of lead concentrations from fountains and faucets in each round of non-residential testing

When the expected use of the outlets was considered, there was a strong indication that the most realistic risks of lead exposure were from a limited collection of drinking fountains. The fountains where the highest lead levels were found were installed prior to the implementation of the LCCA in 1988, which was enacted to reduce lead exposure in schools (USEPA, 2006). Several particular fountain manufacturers stood out as having higher incidences of elevated lead, suggesting the fountains themselves were likely the source of lead. It would prove useful for a water supplier to keep track of manufacturers of fountains and faucets which tend to have elevated lead, to provide to other non-residential building owners who intend to conduct lead testing, in order to help determine sites of high risk and particular importance for testing.

The results found from the non-residential testing illustrate the degree of variability of lead concentrations to be found, even within a single building, and demonstrate the importance of the outlet itself as a source of lead. Establishment of a non-residential testing protocol can be complex, as the intent is to ensure the water is safe from high-use sites, while many of the most problematic sites may be those sites which encounter infrequent use. It is therefore critical to include a variety of outlets, varying between faucets and fountains, new and old, high use and low, and fountains with and without cooling reservoirs. To improve the efficiency of a lead monitoring program in non-residential buildings, sites must be investigated prior to sampling to determine age of outlet piping, usage patterns at the sites, and the manufacturer and model of outlets, in order to determine which sites have a higher expected risk so that priority can be directed to sampling those sites.

3.4 Conclusions

Three rounds of a lead monitoring program were conducted at an academic institution in Halifax, NS. In each of the three rounds, approximately 30 residential and 100 non-residential sites, were tested in accordance to the first tier testing protocol outlined in the Health Canada Guidance on Controlling Corrosion in Drinking Water Distribution Systems for the two exposure patterns (Health Canada, 2009). The first two rounds of the residential testing suggested the corrosion control implemented by Halifax Water was effective to maintain low lead levels; however, the action level was exceeded in the third round of testing. Interestingly, the third round was conducted in the winter, and higher lead concentrations were also observed in the winter in the non-residential testing. This is contradictory to what is typically expected, as lead concentrations generally tend to be greater in the summer. Health Canada (2009) and the USEPA (2010) both recommend utilities conduct annual monitoring during the summer to account for the worst case scenario. The seasonal fluctuation is expected to result from fluctuation of aluminum residuals in the finished water exiting the treatment plant, but could also result from slightly elevated NOM levels in the winter.

The same seasonal fluctuations of lead concentrations were found in the non-residential buildings as in the residential buildings, as lead levels at a given site tended to be higher during the February monitoring events compared to the October testing. High lead concentrations were found in the non-residential buildings, even in monitoring periods when residential testing characterized the water supplied by Halifax Water as non-corrosive. High lead was found at faucets which seemed to receive infrequent usage, as well as at several drinking fountains which were all of similar vintage and located within a few select buildings. Frequency of use, age, and outlet manufacturer were variables which were associated with elevated lead levels. Recognition of the variables which lead to elevated lead is important in optimizing the ability of a monitoring program to discover lead level exceedences with limited resources. Creation of non-residential databases by water suppliers could prove valuable, as they may allow the utility to provide meaningful information to school boards or other building owners who need to conduct monitoring programs with limited funds. Lead problems associated with drinking fountains were studied in greater detail and are discussed in the ensuing chapter.

Chapter 4: Drinking Fountain Investigation

4.1 Introduction

Numerous cases of elevated lead in institutional or non-residential buildings have been reported in recent years (Cartier et al, 2012b; Deshommes et al, 2012; Elfland et al, 2010; Boyd et al, 2008b; Boyd et al, 2008c). Sources of lead in these buildings may include inline brass devices (Elfland et al, 2010); leaded-solder; as well as end point devices such as faucets and drinking water fountains (Cartier et al, 2012b; Boyd et al, 2008b). Lead concentrations in non-residential buildings can be highly variable and difficult to predict (Maas et al, 1994). This is because of conditions which are unique to non-residential buildings such as: long stagnation times; long plumbing networks; infrequent and inconsistent usage patterns; and the prevalence of leaded materials (USEPA, 2006). Because lead sources and flow conditions differ so greatly from residential conditions, compliance with residential monitoring and concentrations does not ensure that a lead contamination issue will not exist in a non-residential building.

Often, the reported cases of elevated lead in drinking water in non-residential buildings are from school testing programs. In Canada, drinking water is provincially regulated, and Ontario is the only province to regulate lead monitoring in non-residential buildings (Barn and Kosatsky, 2011). Ontario regulations require annual testing of at least one site of drinking water in every school in the province (Government of Ontario, 2010a). Health Canada (2009) provides direction for implementing a monitoring program in non-residential buildings, but the monitoring and corrective actions are the responsibility of the building owner or responsible authority (i.e. a school board), and therefore there is no requirement for the water supplier to conduct the monitoring. In the US, the USEPA was mandated by the LCCA to develop a lead monitoring for schools; however, school testing is under the responsibility of the state, and therefore monitoring and compliance varies by state (USEPA, 2006).

Drinking fountains containing leaded components may pose a particular risk because they are prevalent in schools which have high occupancies of children who are at the highest risk of the adverse effects from lead exposure; they are associated with intermittent use and long stagnation periods; they often have more soldered joints then typical faucets; and the small pipes in fountains increase contact between the exposed surface and the water (Barn and Kosatsky, 2011; Canfield et al, 2003). Fountains often contain a number of brass components which typically contain between two to eight percent lead by mass, and have been found to be a significant source of lead even in sites with lead services and leaded solders (Kimbrough, 2001). Additionally, older fountains with refrigeration units may even contain cooling tanks which contain lead (USEPA, 2006). Leaded tanks are of particular concern because the large volume could result in extended periods of contact between the water and the lead within the tank.

Following the implementation of the LCCA, an extensive list was released of cooling tanks which contained lead (USEPA, 1990). While the majority of these tanks contained lead soldered joints, the highest risk coolers were identified in a limited list of six models which contained lead lined cooling tanks, listed in Table 4.1. In the US, the Consumer Product Safety Commission (CPSC) ordered a recall of all units identified in the list of coolers potentially containing lead lined tanks (USEPA, 2006). These cooling tanks were discovered through a USEPA investigation where a limited number of water coolers were cut open and tested (USEPA, 1990). Models which were found to have at least one unit with a lead-lined tank were included in the list. Not necessarily every unit of the listed models contain lead lined tanks; alternatively, it is unlikely that every model which was ever assembled with a lead lined tank was discovered in this study, and therefore it is reasonable to expect that more models with lead-lined tanks may exist.

Table 4.1: List of models potentially containing lead lined cooling tanks (adapted from USEPA, 1990)

Manufacturer	Model
Halsey Taylor	WM8A
Halsey Taylor	WT8A
Halsey Taylor	GC10ACR
Halsey Taylor	GC10A
Halsey Taylor	GC5A
Halsey Taylor	RWM13A

Elevated lead found in samples drawn from drinking fountains does not imply that the fountain was the lead source (Elfland et al, 2010). However, during a lead monitoring program conducted as part of this research, it was found that several of the absolute highest lead concentrations were in samples drawn from fountains, and therefore the contributions of the fountains came into question.

Lead concentrations as a function of fountain manufacturer from the first round of the non-residential monitoring program are presented in Figure 4.2. Interestingly, several of the samples with highest lead concentrations were drawn from fountains manufactured by Halsey Taylor, which was identified as the manufacturer of the lead-lined cooling tanks (USEPA, 1990). This fact was actually originally overlooked because of branded components on several of the Halsey Taylor fountains. The branded front plate gave the appearance that the fountains were constructed by another manufacturer. It wasn’t until they were opened that the registration plate became visible, and it was found that they were not simply Halsey Taylor fountains, but also of the same model line, RWM, as one of the models identified to potentially contain lead lined tanks.

The objective of this research was to understand the effects of fountains on lead levels in drinking water in institutional buildings. The investigation focused on several sites with similar plumbing characteristics, including identical fountains, yet there was a significant variation in lead levels from one location to the next similar location. The study was conducted to identify the specific components which were the major sources of lead contamination, as well as to determine the factors that caused one fountain to have dissimilar lead release trends from a nearby, identical fountain.

4.2 Materials and Methods

Description of test area. The same source water was used for the fountain investigation as the lead monitoring program. The sites studied in this investigation were also sampled in the lead monitoring program. The sites were selected because of elevated lead results in the 250 mL first-draw sample of the monitoring program.

Testing was conducted at Halsey Taylor RWM model fountains, which had been banned and recalled in the US for potentially containing lead-lined cooling tanks, in several buildings, as well as a fountain manufactured by Crane which produced high concentrations of lead in first-draw 250 mL samples. The two models which were the focus of this study are shown in Figure 4.1, where the RWM model is shown in (a) and the Crane fountain is shown in (b). The fountains at the centre of this study were installed in the 1960s.

Figure 4.1: The fountains at the focus of this study (a) Halsey Taylor RWM model and (b) Crane

Experimental Methods. All field testing in this chapter was conducted after a predetermined stagnation period. For most tests, the stagnation time ranged from 16 to 24 hours; however, there were several tests conducted following shorter stagnation to determine the rate of lead release. Prior to the stagnation period, fountains were always flushed for a minimum of three minutes. A testing method, known as sequential sampling, frequently employed to develop lead (or other metals) profiles, was followed.

Testing was conducted by collecting several consecutive samples following stagnation. The majority of sequential sampling conducted throughout this investigation involved four consecutive samples of 250 mL volume, followed by two 1 L volumes, for a total of three litres of sampling. However, there were several instances where smaller volumes were collected to gain a better understanding of the lead sources. Samples were shaken immediately after they were collected and various aliquots were collected. Aliquots of roughly 100 mL were withdrawn from the first draw sample, the third sample, and the 5th sample, in order to have a separate volume which could be filtered in the lab. Aliquots of roughly 10 mL were collected for ion chromatography from the second and fourth samples. Additionally aliquots of roughly 100 mL were collected from the fifth sample to conduct field measurements for pH, temperature, free chlorine residual, and turbidity.

As follow-up on one of the fountains, brass components were dissolved in acid to determine the approximate relative percent of lead by mass for each component. This was conducted by dissolving a fragment of known mass of each component into a predetermined volume of aqua regia (1:3 volume ratio of HNO_3:HCl). This was then heated to 85° C for roughly 30 minutes or until the entire fragment was dissolved. The sample was then analysed by ICPMS, which required several iterations of 10x serial dilutions in order to bring the various elements to within the detection limits of the ICPMS.

Analytical Methods. Measurements for temperature and pH were determined using an Orion pH probe, which was calibrated daily using standards of pH 4, and pH 10. Turbidity was measured using a Hach 2100P, portable turbidimeter, and free chlorine was measured using a Hach pocket colorimeter, using the DBP method. Samples were kept chilled and transported to the laboratory for analysis of metals, organic carbon, and ion concentrations. Samples were stored at 4° C. Metals were analysed by ICPMS using a Thermo Fisher X Series 2 ICPMS using Standard Method 3125, with detectable limits of 0.4 μg/L, 0.7 μg/L, 0.6 μg/L, 7 μg/L, and 0.6 μg/L for lead, copper, zinc, iron, and tin respectively. Phosphate, chloride, and sulfate ions were measured within two days of sample collection using a Metrohm 761 Compact IC with 788 Filtration Sample

Processor. Total and dissolved organic carbon were analysed by a Shimadzu TOC-VCSH TOC Analyzer. Dissolved metals and organic carbon were determined from samples which were filtered through 0.45 µm polysulfone membrane filters.

Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) analysis was conducted on several corrosion layer samples. The samples were scraped from the interior of pipe walls using scoopulas, and mounted on SEM stubs. To prevent charge build-up, the samples were coated with gold palladium using a Polaron SC7620 Mini Sputter Coater, using a plasma current of 18 mA for 120 seconds. SEM and EDS analysis was performed using an Hitachi S-4700 FEG Scanning Electron Microscope, using an accelerating voltage of 20 kV and an emission current of 8.5 µA.

4.3 Results and Discussion

Leaded Cooling Tanks. The first round of the campus-wide lead monitoring program unveiled the presence of a lead issue in several larger, non-residential buildings, particularly with certain drinking fountains. One fountain manufacturer in particular, Halsey Taylor, was associated with three of the four highest lead concentrations encountered from drinking fountains in the first round, as shown in Figure 4.2.

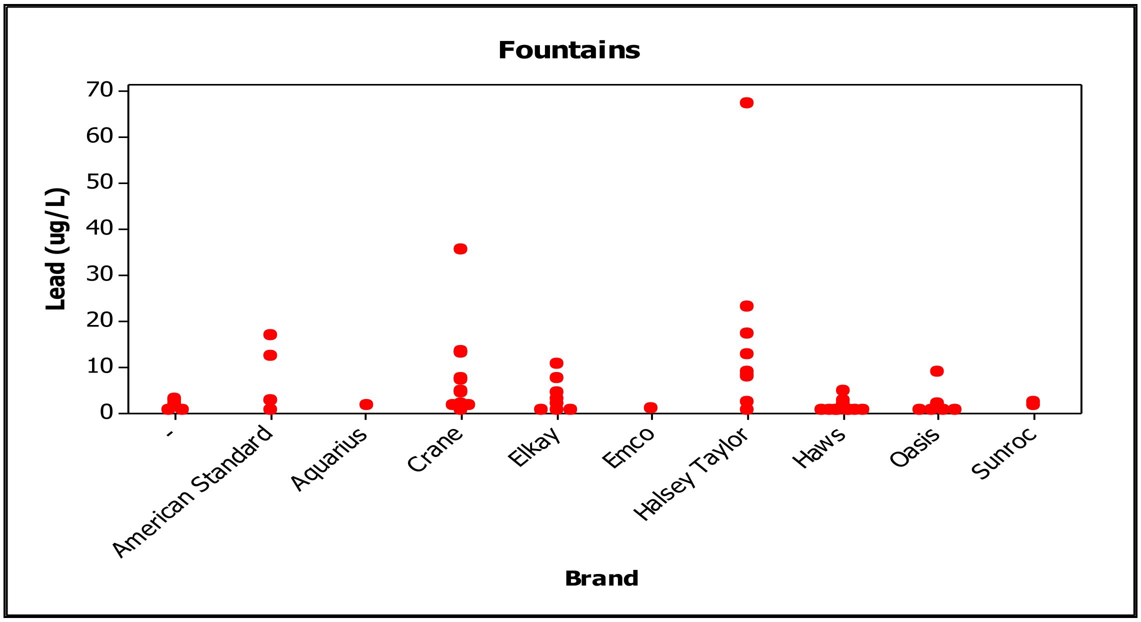

Figure 4.2: Summary of lead concentrations from drinking fountains in first round of non-residential lead monitoring

Originally, these three fountains were identified as manufactured by a company which could not be found through any online searches because of the label on the front plate, so particular interest was given to these fountains. After the fountains were disassembled, it was found that these fountains were in fact a particular model which had been banned and recalled in the US for potentially containing lead lined cooling reservoirs (USEPA, 1990). The lead lined cooling reservoirs were due to occasional process errors during manufacturing of the tanks. Occasionally, the molten tin which the reservoirs were dipped in was contaminated with lead; therefore, a given unit of a model identified by the USEPA does not guarantee the presence of a lead lined tank, but instead suggests it as a possibility.

Table 4.2: Summary of the location of the RWM model fountains and all the relevant fountains of this study

Fountain Type	Building	Floor where situated	Site Name
Halsey Taylor RWM	A	1	A1
		3	A2
		4	A3
	B	4	B4
		5	B5
	C	2	C2
		3	C3
		4	C4
Crane	D	0	D0
		1	D1
		2	D2

A search of the campus was conducted to identify the presence of other fountains included in the list of models which may contain the leaded tanks. In addition to the three which were identified as sources of high lead through the monitoring program, five others were found with the same model number. The location of the eight fountains and their site identifiers are listed in Table 4.2. The other three fountains manufactured by Crane are also presented in the table. Sequential sampling was conducted on all of the RWM model fountains and four were found to have high lead, suggesting that the presence of a leaded tank was a possibility, or perhaps interior brass was releasing significant quantities of lead.

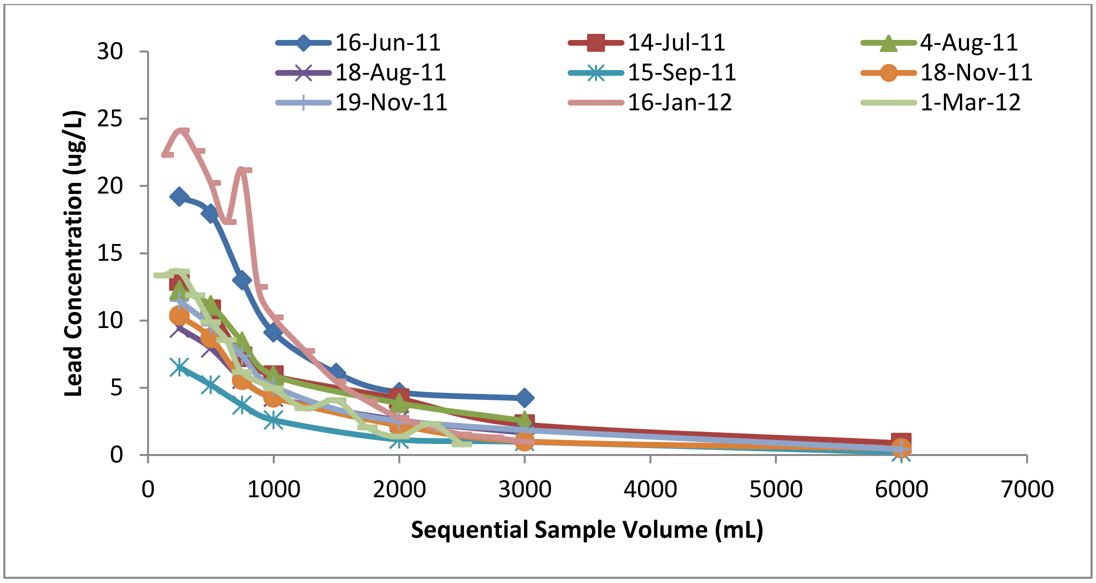

Figure 4.3: Sequential sampling lead results from RWM model fountain from site A1

Lead results of sequential sampling from an RWM fountain located on the first floor in building A (A1), are presented in Figure 4.3. Consecutive sample volumes are displayed on the x-axis, and the lead concentrations are presented on the y-axis. To help understand the lead profiles, a photograph of the interior of the RWM fountain is shown in Figure 4.4. Additionally, the schematic diagram in Figure 4.5 provides an estimate of the location of sequential sample volumes in order to determine the sources of lead, copper, and zinc. It should be noted that the volumes with respect to location of stagnation have not been confirmed. The diagram is used to provide an estimate of the source of metals and was developed based entirely on interpretations of the data.

Figure 4.4: Interior of RWM model fountains

From the lead profiles (Figure 4.3), elevated lead levels in the initial 500 mL found in repeated sampling suggested the presence of the leaded cooling tank. The peak was followed by a decrease in lead concentration through the subsequent litre, which was then followed by a relatively stable lead concentration through the following samples. Throughout the year of sampling, it is clear that the profile remained quite consistent; however, the quantity of lead in the first litre varied quite dramatically from concentrations as high as 25 µg/L in a January 2012 sample, to as low as 5 µg/L in samples collected in September 2011.

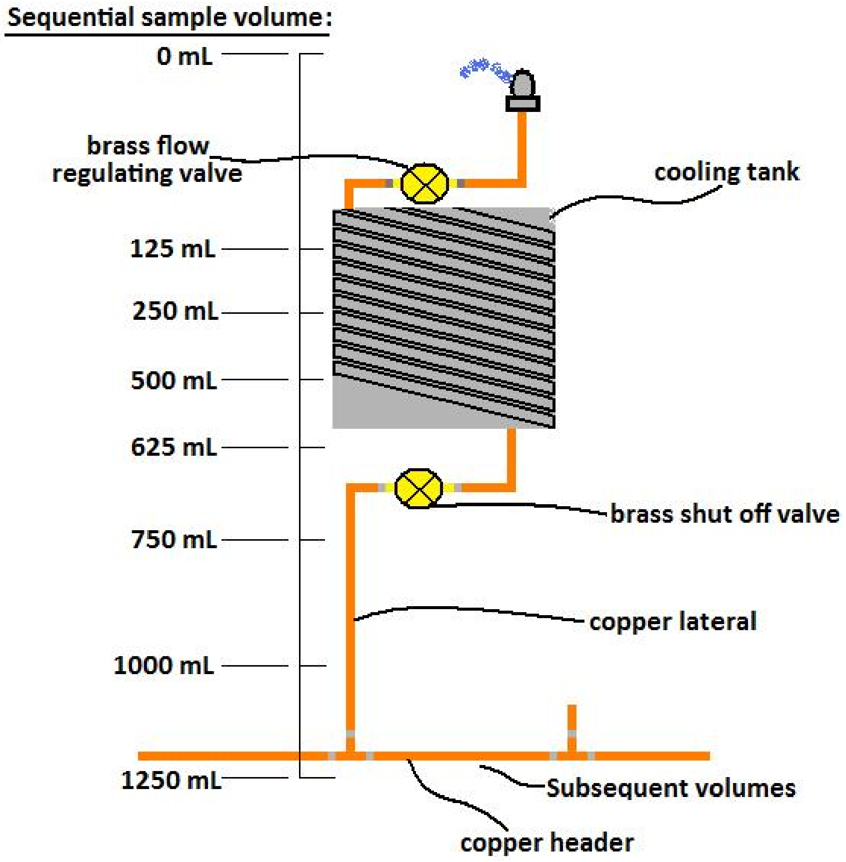

Figure 4.5: Estimated origin of sequential sample volumes in RWM model fountains

Smaller volumes, such as 250 mL, 125 mL, or even 50 mL samples, may be used to pin point major sources of lead, whereas larger volumes, such as 1 L samples can be used as a means of identifying areas of elevated lead levels. Two sampling events, January 2012 and March 2012, were conducted using smaller volume samples of 125 mL, and in both of these events there was a peak in lead concentration in the second sample containing the volume between 125 mL to 250 mL. This is likely because the initial volume- of perhaps less than 50 mL- contained water which stagnated in the copper pipe connecting the tank to the bubbler, and in this small section, the only source of lead would be the flow regulator valve. Therefore, the first volume, which would contain some sample which stagnated in the cooling tank, would be diluted by the water which stagnated between the tank and the bubbler. The subsequent sample would contain water which entirely stagnated in the cooling tank and would be the cause of the lead peak between 125 mL and 250 mL. Following this peak, the lead concentration begins to decrease, as samples begin to contain a mixture of the water from the tank and the water from upstream of the tank. A secondary peak, only shown in the January 2012 sample event, in the sample bottle containing the 625 mL – 750 mL sample, likely results from lead released from the shutoff valve, which is connected inline directly before water enters the tank.

The presence of a lead lined tank is supported by copper profile, shown in Figure 4.6. The peak in copper concentrations is delayed compared to the lead peak, and occurs between the 750 mL volume and the 1000 mL volume. This suggests that the volume of the tank is less than 750 mL and copper concentrations prior to the peak likely result from diffusion of copper from piping upstream of the tank, from the leaching of the brass flow regulator located downstream of the tank, and from any scales formed from copper deposits within the tank. Copper concentrations are occasionally lower in fully flushed samples, likely due to lesser stagnation time than the water in earlier volumes, thanks to flushing from other outlets within the building.

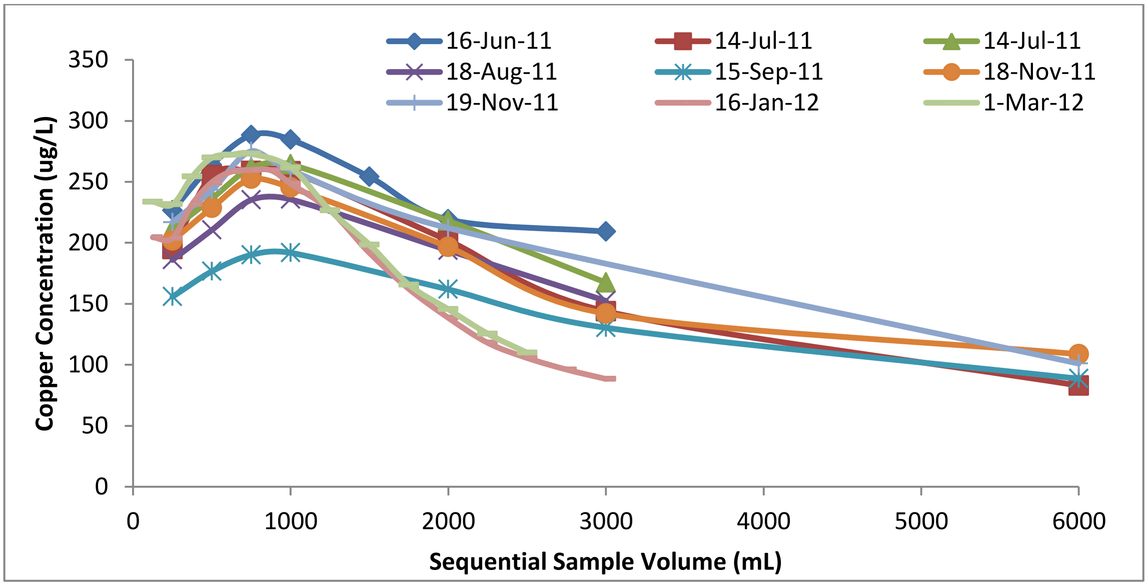

Figure 4.6: Sequential copper concentrations from RWM model fountain located at site A1

First draw samples were collected from site A1 following various stagnation times to determine the rate at which lead levels increased within the fountain. Over the span of two days, the fountain would be tested following one, three, six, and roughly 24 hours of stagnation time. The maximum duration of stagnation testing was selected as 24 hours for two main purposes: durations greater than 24 hours increased the likelihood of an individual using the fountain, thereby flushing the system and influencing the testing results; and previous studies have found that increases in lead levels, begin to stabilize following roughly overnight stagnation times (Schock et al, 1996). Sampling events where only a single test was conducted, such as individual sequential sampling events, were not included due to the variation in lead concentrations from one event to another (ie. a test in June could not be compared directly with a test in August). Over the duration of this study first draw concentrations ranged from as high as 22 μg/L to as low as 6 μg/L at the given fountain.

The stagnation profile from site A1, shown in Figure 4.7, illustrates the continuous increase in lead concentrations throughout the entire 24 hour period. An exponential curve was used because it has been found that lead and copper concentrations tend to increase exponentially with stagnation time (Lytle and Schock, 2000). Despite a continued increase even up to 24 hours, the rate of increase reduces in the final 18 hours compared to the rapid increase in the initial six hours. Lead concentrations following six hours of stagnation were roughly equal to 50% of the value following 24 hours. This is similar to experiments conducted on aged lead pipes, where 50 – 70% of the maximum concentrations were observed within 10 hours of stagnation (Lytle and Schock, 2000). In the study on lead pipes, lead concentrations increased with increasing stagnation times up to 90 hours. This is not unexpected, as short duration stagnations of under 24 hours is commonly encountered with fresh lead pipe; however, in older, scaled lead, equilibrium can take a much greater time (Schock, 1990).

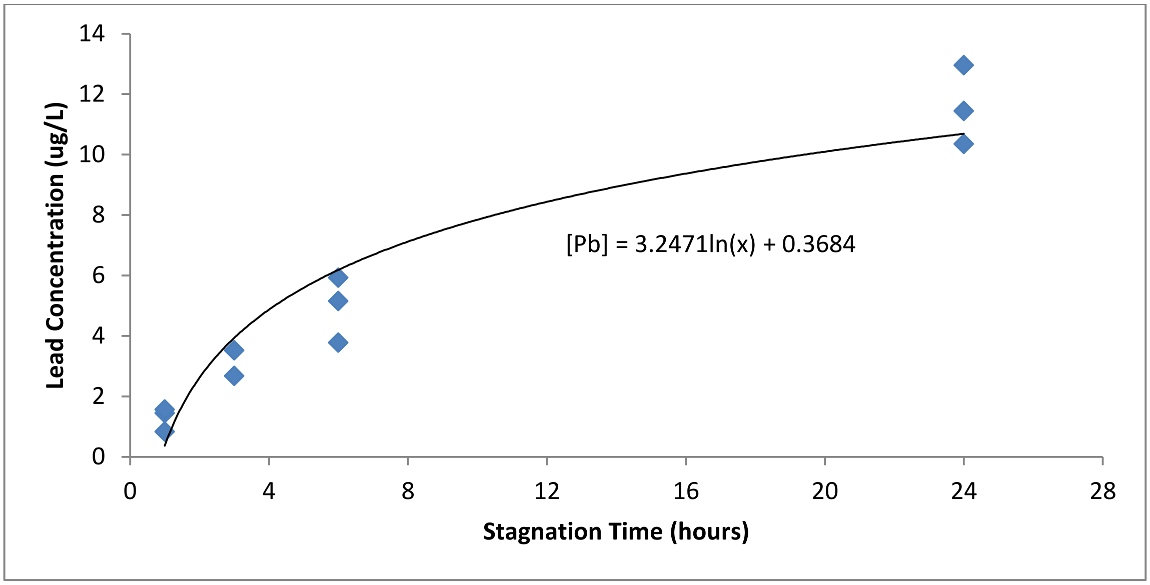

Figure 4.7: Lead concentrations from the RWM model at site A1 following various stagnation times

It is quite likely that concentrations at this fountain would have been greater following longer stagnation times, but field sampling following longer stagnation of this fountain was not practical. Based on the results presented in Figure 4.7, lead levels at this site could be expected to be quite high following weekend stagnation periods which could include stagnation periods as long as 65 hours. Rapid increases in lead levels following short stagnation times suggests that high lead could be expected in a setting, such as a school, where intermittent water usage could be expected. This is particularly true if the infield drawn volumes are small in comparison to the tank volume of roughly 500 mL, which would result in continuous plugs of water which stagnated for significant amounts of time within the cooling tank.

A seasonal trend was observed during the fountain study which was similar to the trend observed in the monitoring program. The elevated lead levels found in the winter compared to the summer were unexpected, as higher lead levels are typically found during the summer months between June and September (USEPA, 2010). The seasonal trend was often quite pronounced. In the case of site C15, a first draw sample collected in the winter had a lead concentration of over 60 µg/L, whereas numerous samples collected during the summer were below 10 µg/L. The seasonal lead trends were attributed to seasonal trends in residual aluminum levels in the water leaving the treatment plant.

Positive correlations between particulate aluminum and particulate lead following stagnation have been demonstrated, suggesting that lead may adsorb to aluminum oxides (Knowles, 2011). A plot of the residual aluminum levels leaving the treatment plant is shown in Figure 4.8, along with lead levels measured at site A1 and C3 fountains during the timeframe. The aluminum residuals follow a seasonal cycle, fluctuating between high in the winter and low in the summer, which is comparably matched by the lead levels measured at the two sites. Throughout the time period, the aluminum concentration was kept below the operational guidance value for a direct filtration treatment plant of 0.2 mg/L (Health Canada, 1996); however, the concentrations during the winter were typically more than double the summer concentrations. The fountain data for this figure is limited, because there were only a few sites which were tested frequently enough to adequately demonstrate any correlation between the two parameters; unfortunately the limited lead data from any given fountain was insufficient to statistically confirm if the two parameters were in fact correlated.

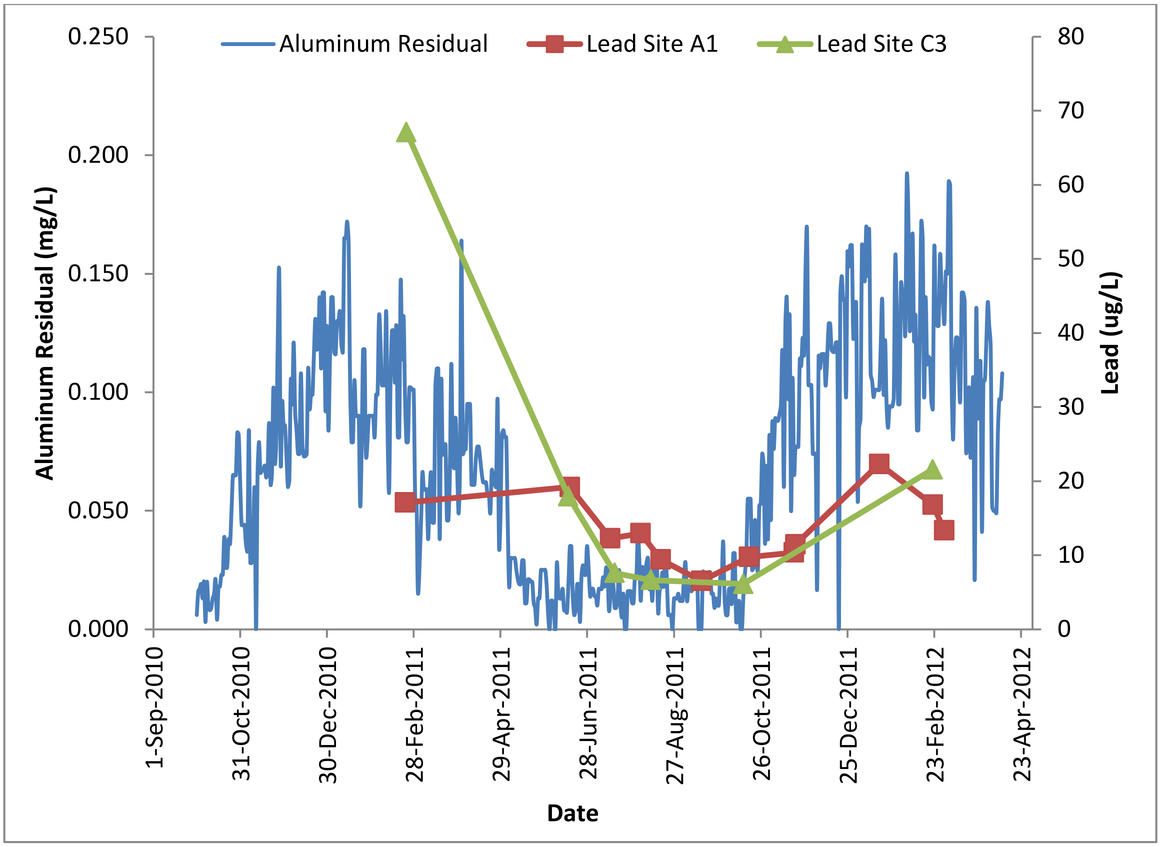

Figure 4.8: Aluminum residual concentrations in water leaving JDKWSP paired with lead measurements at select sites tested throughout the given timeframe

Various other reasons for the seasonal variability were considered and dismissed in the lead monitoring program. Improvement of corrosion inhibitor performance with increasing temperature was considered; however, previous inhibitor research at JDKWSP demonstrated that temperature did not have an effect on lead release (Woszczynski, 2011). Reversed temperature fluctuations within buildings due to overheating in the winter and over cooling in the summer was another cause which was considered and rejected. Numerous fountains with cooling tanks demonstrated the seasonal trend, despite producing water of consistent temperature throughout the year. This theory was also disproved in the monitoring program, where first draw temperature measurements in residential buildings were higher in the summer. One more theory which has neither been confirmed nor refuted is that increased water demand during the summer results in more consistent water quality during the summer. As a result, the water would have less variation in DO, free chlorine levels, and phosphate concentrations, and therefore may affect scale formation.

Another RWM model fountain located in Building A (site A3) also exceeded the lead action level in the preliminary round of non-residential testing with a concentration of 23 µg/L. As a result, the fountain was removed from service by covering it with a bag and attaching a sign to it which labelled it out of order. Profile sampling was conducted at this site three weeks later using the same protocol as for site A1, including flushing before sampling. Throughout the weeks when the fountain was out of operation, the corrosion scales destabilized resulting in significantly high lead concentrations in the two sample events collected June 16 and July 7, shown in Figure 4.9. The destabilization of the scales was evidenced through the very high fractions of particulate lead. In the samples which were measured for total and dissolved lead during the June and July sampling events, every sample's lead concentration was comprised of roughly 90% or higher as particulates (Appendix B). In fact, the soluble lead concentrations during this time through sequential samples were very similar to the levels found in the RWM model fountain at site A1. The equivalent levels of soluble lead following the same stagnation periods suggests similar solubility and release rates, and therefore the nature of the corrosion scales themselves likely did not change. The difference in lead levels therefore likely resulted from direct sloughing off of the scales.

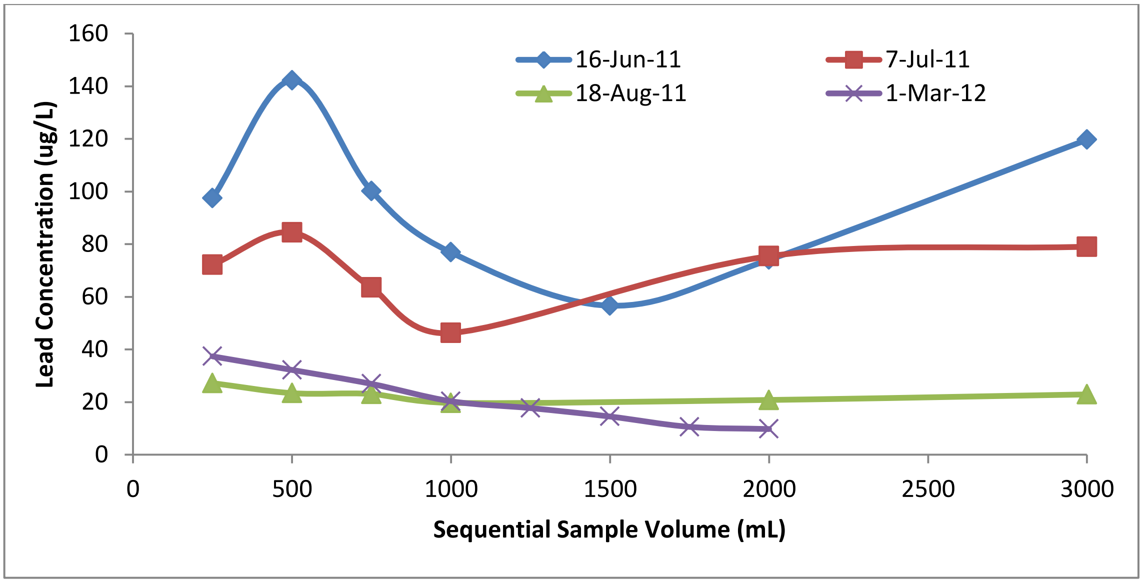

Figure 4.9: Sequential sampling lead concentrations from RWM model fountain, site A3

Destabilization of the corrosion scales because of lack of use may have resulted from a variety of reasons, including: changes in the water's ORP due to inconsistent DO concentrations and diminished free chlorine residual; potential changes in pH from the long periods in the pipe; and changes or depletion of the phosphate inhibitor (Edwards et al, 2002; Schock, 1990). Further evidence of release of corrosion scales was found by examining copper and iron concentrations, which both closely followed the lead levels, as shown in Figure 4.10. It is expected that the scale would have a significant mass of lead, copper, and iron from corrosion of the underlying pipe and deposition of metals from upstream. The particles which likely sloughed off the pipe wall therefore proportionally affected the three metals concentrations. The correlation between iron and copper, and iron and lead, suggests the high metal concentrations are not a result of brass corrosion, as iron is not a typical indicator of brass corrosion. The lack of correlation between lead and zinc levels (not shown), and the lack of negative correlation between zinc and copper, also suggests that the similar concentration profiles are not a result of brass corrosion (Kimbrough, 2007; Kimbrough, 2001).

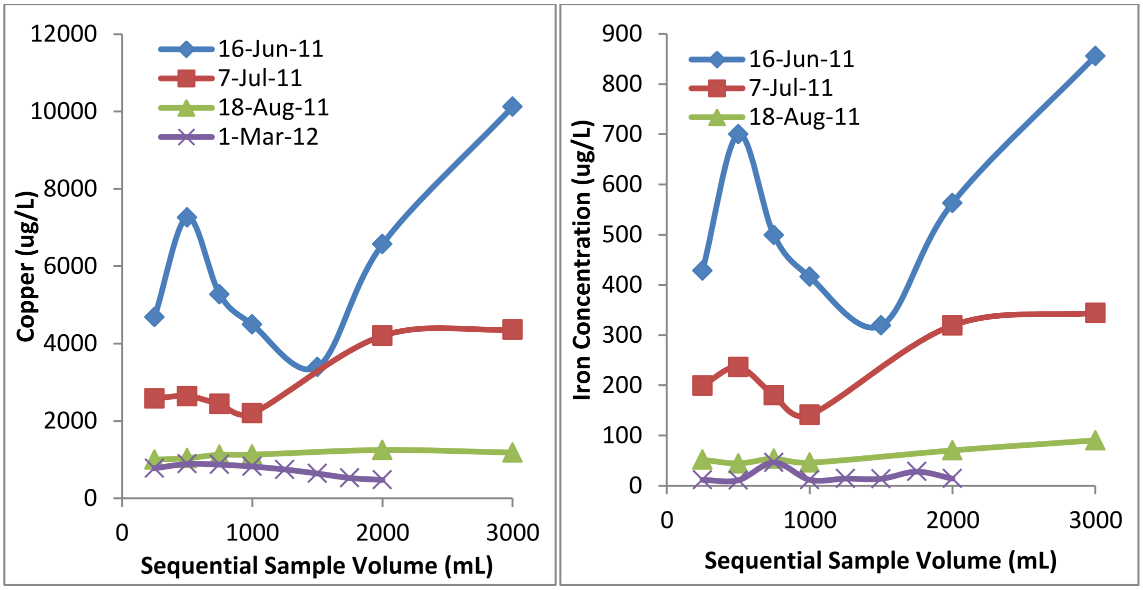

Figure 4.10: Sequential sampling copper and iron concentrations from RWM model fountain, site A3

At some point in time between the sampling conducted on July 7th and August 18th, the cover and sign were removed from the fountain, so it was mistakenly put back into use. During this time, the lead levels and fractions of particulates decreased; although the particulate levels were still quite high compared to other testing sites. Ultimately the fountain was removed and replaced. Ideally, testing would have been conducted in between removal and replacement to determine the contribution of upstream sources. The new fountains installed at the university contain built in NSF 53 certified lead filters, so the lead levels were significantly decreased at this site as shown in Figure 4.11. NSF 53 filters have been shown to effectively remove both dissolved and particulate lead, and are acknowledged as a suitable means of reducing lead exposure in large buildings, provided proper maintenance procedures are followed (Deshommes et al, 2012; Deshommes et al, 2010). Similar results were found at site C3, where the RWM model fountain was also removed and the lead levels were significantly reduced.

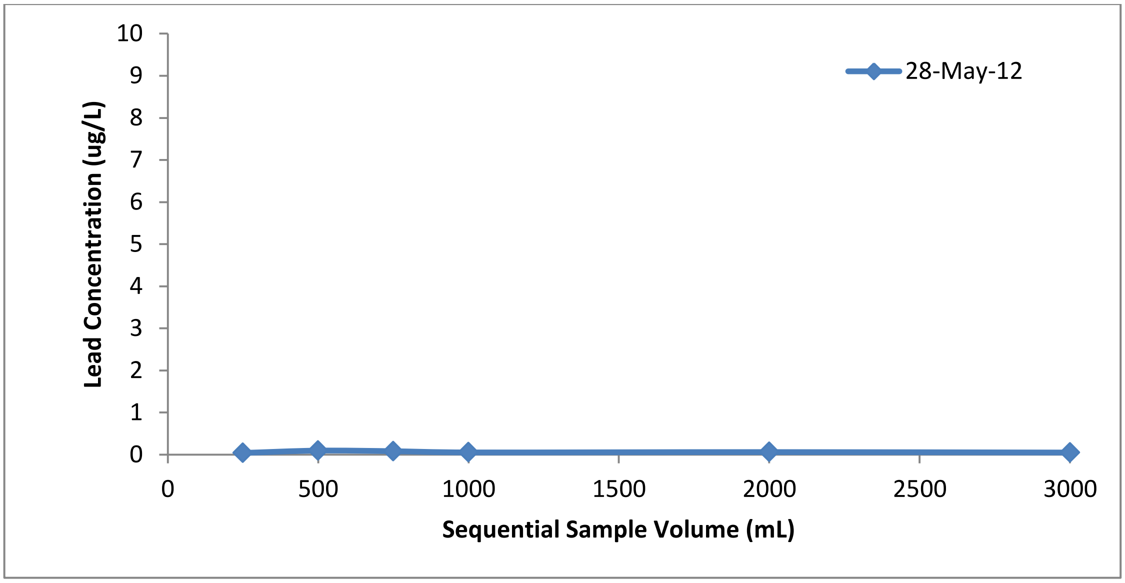

Figure 4.11: Sequential sampling lead concentrations from fountain which replaced the RWM model fountain, site A3

Brass Fountain Components as a Source of Lead.

The other fountain at the focus of this study was an old fountain manufactured by Crane, located on the ground floor of building D, which contained elevated lead in the first draw sample collected during the first round of the non-residential sampling. This same fountain was found on the first and second floor of the same building and the water collected from those fountains was well below the action level. From discussions with maintenance staff and individuals who use the building, it was found that the fountains on the first and second floor received regular use, but the one on the ground floor was rarely used. Similarly to the high lead release from site A3, infrequent use was deemed to be cause of the elevated lead at site D0. The same explanations have been cited in this case, including inconsistent DO concentrations and diminished free chlorine residuals; changes in pH; increased temperature from building heating; and changes to the inhibitor and overall diminishment of phosphate (Edwards et al, 2002; Schock, 1990).

Sequential sampling was conducted on the three sites in building D, and results are presented in Figure 4.12. The peak in the initial volume from all three sites indicates that all three fountains released lead. The site on the ground floor simply released a significantly greater amount during the equal stagnation times. At all sites, lead levels remained low in all flushed samples. The fountain on the ground floor was eventually removed and not replaced because it was infrequently used.

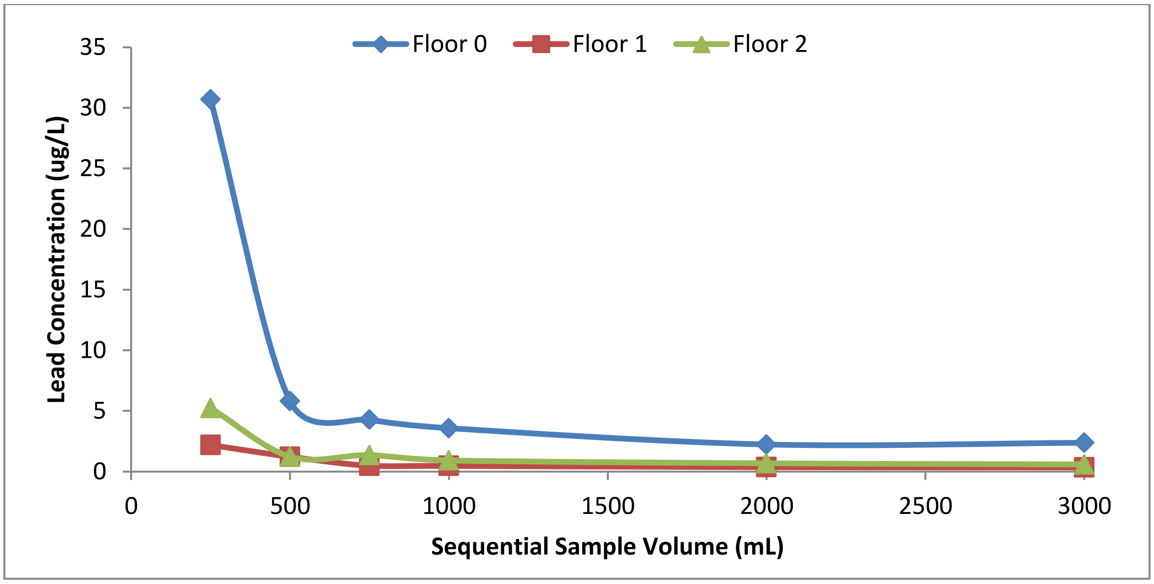

Figure 4.12: Sequential sampling lead results from three fountains of same model, located in building D

The components are shown in Figure 4.13, and brass segments are highlighted by the red circles. The large amount of brass components used for this fountain explain the elevated lead levels in the first sequential sample volume from all three fountains. Brasses used in plumbing typically contain between two to eight percent lead by mass (Health Canada, 2009). The fountain was also installed in 1968, so it is more than likely all soldered joints would have been connected using lead solder; however, the majority of the connections within the fountain were threaded, so brass was likely the primary lead source. Segments of each component were heat digested in concentrated acid to determine a relative metal composition. It was found that segments one, four, and six all contained greater than six percent lead by mass, and segment three had roughly three percent lead by mass. It should be noted that this was only conducted on one fragment of each segment and the repeated dilutions created significant measurement error. Despite the imprecision, the analysis provided valuable insight regarding the amount of lead present within the fountain.

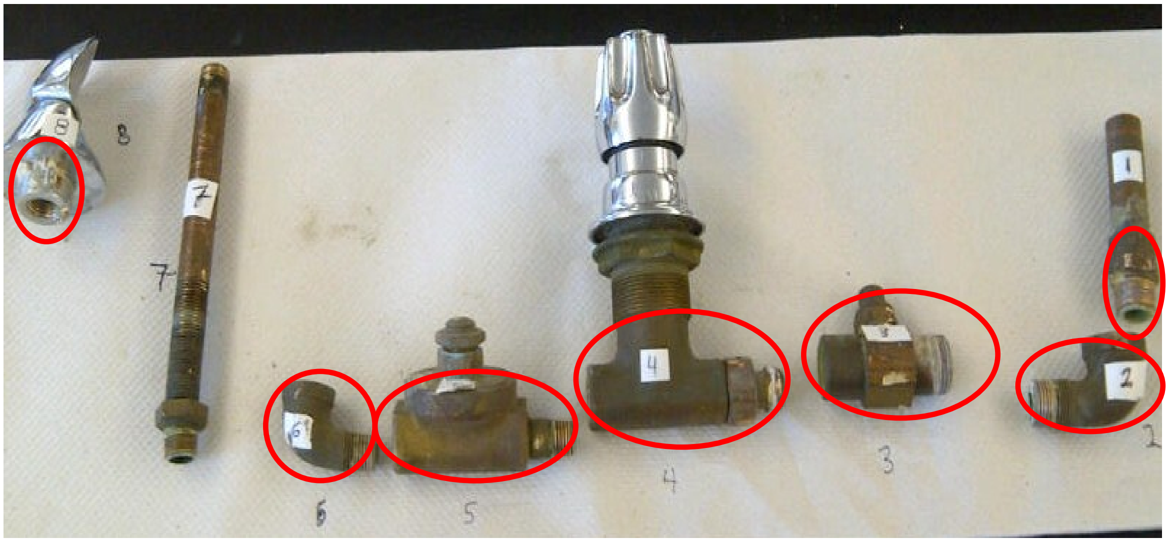

Figure 4.13: Photograph of the interior components of the fountain which was removed from the site D0, brass components are highlighted by the red circles

Evidently, the fountain components were a significant source of lead. Interestingly, the volume of the fountain components totalled little more than 40 mL, so it is likely the fountain released the majority of the mass of lead in this small volume. The first drink taken from this fountain after a few hours stagnation would therefore have a significant mass of lead, regardless of how small the amount drawn.

Dump and fill testing following eight hour stagnation was completed on the individual components to determine the relative lead contribution of each component. The average concentrations in the samples from each component are shown in Figure 4.14. To estimate the relative contribution of each component to the field concentrations in a 250 mL sample, mass balances were performed. For each mass balance, the component being evaluated was assumed to be the sole contributor of lead to the 250 mL sample. The results are presented in Table 4.3. Similarly to work conducted by Boyd and colleagues (2008b), the components which released the greatest amount of lead were the components with mechanical moving parts, such as the shutoff valve (segment three) and the operational valve (segment four). The 90° street elbow, segment six, also released a significant amount of lead, which was not a surprise because of its very high lead content.

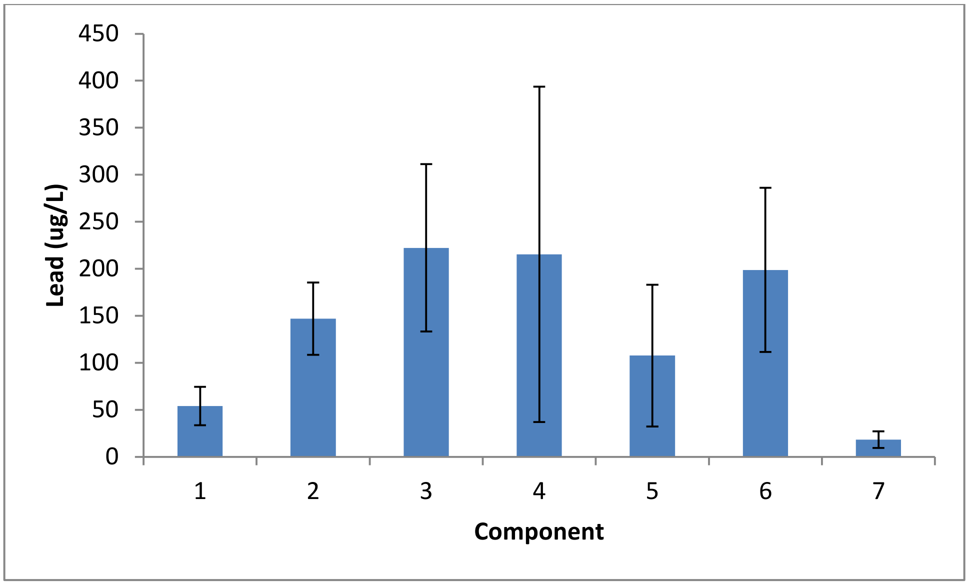

Figure 4.14: Average lead concentration from each component of the removed fountain during dump and fill testing

The individual contributions are listed in Table 4.3, and when summed, add up to 21.4 µg/L, which is in fact reasonably close to the field measurements collected from the three samples of 35.2, 30.7, and 48.9 µg/L. The discrepancy may result from the frequent water changes over the period of the dump and fill study, which provided more consistent water quality than the field conditions where the fountain was rarely used. Additionally, there may have been less particulates in the dump and fill samples because of the absence of flow.

Table 4.3: Relative lead contributions from each component based on dump and fill testing

Component	Volume (mL)	Avg. Lead (µg/L)	Mass of Lead (µg)	Contribution to 250 mL 1st draw sample (µg/L)
1	8.83	53.9	0.476	1.9
2	6.00	147.0	0.882	3.5
3	3.67	222.3	0.815	3.3
4	10.43	215.3	2.25	9.0
5	1.83	107.6	0.197	0.8
6	2.77	198.7	0.550	2.2
7	9.67	18.3	0.177	0.7
			Total	21.4

Corrosion scales from several of the components were scraped and analysed by SEM and EDS. Scrapings were taken from two locations of segment one, at both the copper end and the brass end, as well as scrapings from segments three, six, and seven. The results from the EDS analysis are summarized in Table 4.4. The elemental composition of the scales were comparable between the scales obtained from copper segments and those obtained from brass segments, with the two major differences between the two being the presence of lead in the scrapings from brass, and elevated copper content on the samples obtained directly from the copper segments. Several other elements were detected either in low concentrations or in limited measurements, so they were not included in the table, including: sodium, magnesium, calcium, manganese, and tin. Qualitative information was obtained through SEM images. However, without XRD results, the images cannot be used to confirm the scale mineralogy.

From examination of various SEM work in the literature, some assumptions were drawn. Notably, phosphorus was found at only low levels in the corrosion scales, with typical mass compositions of roughly 0.4%. This level is comparable to phosphorus content in scales developed in the absence of a phosphate inhibitor (Nadagouda et al, 2011). For a scale which formed in water dosed with a phosphate based corrosion inhibitor, phosphorus contents of up to 4% by weight is achievable (Nadagouda et al, 2009). This suggests that adequate phosphate films were unable to develop within this drinking water fountain either because of the low usage or perhaps a greater phosphate dose may be required.

Images obtained through the SEM analysis support the theory that inadequate quantities of phosphate were reaching the fountain, preventing the formation of protective phosphate films. Nadagouda et al (2009) studied corrosion scales developed on lead pipe segments with and without orthophosphate corrosion inhibitors under various pH conditions. They found that at pH of both 7.0 and 7.5, the presence of orthophosphate led to the formation of dendritic, or branchlike, structures, but without the inhibitor, the scales were rather smooth and plate-like, as shown in Figure 4.16. Several SEM images of the scales collected from the D0 fountain are presented in Figure 4.15. In each case, the scales tend to be jagged or plate-like, but the branchlike structures associated with phosphate films were not found through this analysis.

Table 4.4: Percent composition of corrosion scales from selected segments from the fountain removed from site D0

Pipe	Segment	Percent Composition									
Segment	Material	C	O	Al	Si	P	Cl	Fe	Cu	Zn	Pb
1	Copper	29.82 ± 4.89	35.84 ± 4.65	2.45 ± 0.30	1.21 ± 0.38	0.44 ± 0.05	0.63 ± 0.19	1.37 ± 0.65	25.84 ± 0.49	1.79 ± 0.52	0 ± 0
	Brass	32.28 ± 2.91	36.14 ± 0.98	2.00 ± 0.13	0.89 ± 0.28	0.30 ± 0.09	0.47 ± 0.21	1.10 ± 0.34	24.29 ± 2.22	1.91 ± 0.17	0.42 ± 0.69
3	Brass	19.22 ± 10.99	38.71 ± 2.36	2.23 ± 1.15	0.77 ± 0.94	0.45 ± 0.50	0.63 ± 0.36	0.76 ± 0.72	10.86 ± 6.67	25.67 ± 5.50	0.71 ± 0.41
6	Brass	30.47 ± 7.50	37.10 ± 11.41	1.40 ± 1.31	8.04 ± 6.19	0.20 ± 0.17	0.23 ± 0.37	1.07 ± 0.18	13.81 ± 15.34	1.08 ± 0.69	1.74 ± 1.65
7	Copper	26.79 ± 0.79	37.58 ± 1.08	2.77 ± 0.30	1.61 ± 0.47	0.47 ± 0.44	0.50 ± 0	1.02 ± 0.21	26.50 ± 0.65	2.76 ± 0.24	0 ± 0

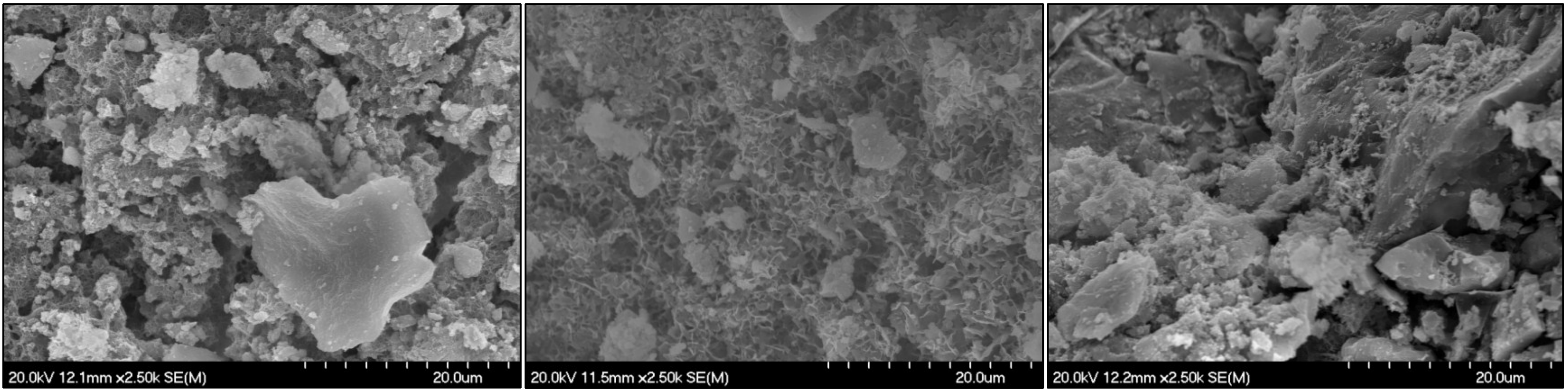

Figure 4.15: SEM images of corrosion scales obtained from various brass segments from the fountain at site D0.

This particular fountain demonstrated the significance of older fountains as a source of lead; even the simpler bubbler style fountains without cooling tanks (USEPA, 2006). This is due to the abundance of brass components which make up the inner workings of these fountains. If the water supplied to these fountains is not corrosive, and the fountain receives regular usage, these fountains may pose a low risk for elevated lead, despite having high amounts of lead present within their components. It is therefore beneficial to monitor the usage of older fountains in non-residential buildings, such as schools. Infrequently used fountains may pose a significant risk for the occasional users, particularly the first user following a weekend of stagnant water.

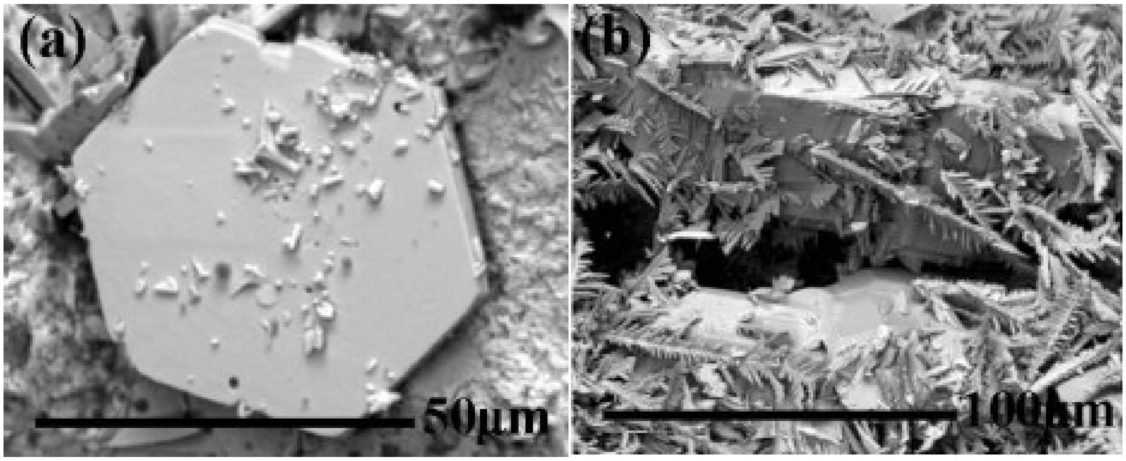

Figure 4.16: SEM images of scales built up on lead pipe in water at pH 7.5 without orthophosphate corrosion inhibitor (left) and in the presence of orthophosphate (right) (Nadagouda et al, 2009)

4.4 Conclusions

Older drinking water fountains were found to be the major source of lead at numerous sites in non-residential buildings. These fountains either encountered infrequent usage, had a large amount of leaded components and lead solders, or both. Many of the fountains tested during this work had an abundance of leaded components, but the majority of these produced samples with low lead concentrations, likely due to adequate film formation thanks to high use. The fountains with the lead lined cooling tanks, Halsey Taylor RWM fountains, were found to release significant lead levels during overnight stagnation, even at sites with frequent usage. Low-use sites with the lead lined tank produced the highest lead levels in this study. Removal of the RWM fountains significantly reduced the lead levels, and consequently the amount of lead exposure at the academic institution of the study. The seasonal trend was observed during this fountain study, with elevated lead levels in the winter and lower lead levels in the summer. In fact, a site predicted to contain a lead lined tank which exceeded the action level in the winter by more than three times (site C3), had lead levels below 10 μg/L repeatedly during summer sampling.

Chapter 5: Effects of Plumbing Flux on Metals Release

5.1 Introduction

Plumbing flux is a corrosive paste which is applied during the soldering of copper and copper alloys in domestic drinking water plumbing. Various studies have been conducted to examine the impacts of flux on drinking water quality and plumbing failures, yet the extent of the problem is not well understood. Corrosive flux residues have been implicated in the corrosion of leaded solders and in initiating the pitting of copper tubing (Myers and Cohen, 1994; Lyon et al, 1977); however, its role remains unclear, as it is scientifically unproven via laboratory experiments (Farooqi et al, 2009). Limited research is available regarding the impact of flux on metal concentrations in drinking water, Recent work in the field of drinking water research has found that the impacts of water soluble flux (WSF) residues on lead release from brass is short lived (Triantafyllidou et al, 2012), but the impacts resulting from non-water soluble fluxes, still used in practice, are not known. The impacts of soldering flux residues are more widely studied in the electronics manufacturing industry. While the type of flux used in this industry is different than that used by plumbers (Hansen et al, 2009), it is worth noting that excessive residues are a common contaminant implicated in the corrosion of electronic assemblies (Jellesen et al, 2010).

Soldering is a common joining method used in domestic plumbing where a molten filling metal forms a bond between components, including copper or copper alloy tubing or fixtures (Humpston et al, 2004). The molten solder flows into the spaces between the two components being joined, and spreads around the joint by capillary action (Blankenbaker, 1978). Prior to 1986, 50:50 lead:tin solders were commonly used in drinking water plumbing; however, this practice was banned because of the significant contributions of these solders to drinking water lead levels measured at the tap (Singley, 1994; Lee et al, 1989). Current solders used for domestic plumbing include tin-antimony and tin-silver-antimony.

The soldering process includes numerous steps which are presented in greater detail in the literature (ASTM, 2010a; CDA, 2006). The basic steps include: cutting, reaming, cleaning and sanding, application of flux, assembly, heating, application of solder, and cleaning.

The quality of the soldering procedure can significantly impact the quality of the joint. Improper soldering temperature can cause the flux to decompose or boil off, which can cause reformation of oxides and will result in poor spreading of the solder (ASTM, 2010a; Humpston et al, 2004). The joint must be properly cleaned of oxides, dust or water vapours to ensure proper wetting (Humpston et al, 2004). Cut ends should be adequately reamed to prevent erosion corrosion, while excessive reaming can cause too large of a gap between the components, preventing proper spreading of the solder around the joint (ASTM, 2010a).

After the joint has been soldered and allowed to cool, it is important to flush the piping in order to remove flux residues as well as metallic debris (Case, 2011). There is no standardized flow rate or flushing duration to ensure the interior is completely cleaned, but Case (2011) suggests flushing at a high rate for 30 minutes. Interestingly, flushing is not included in the ASTM soldering procedure (ASTM, 2010a). The procedure only includes cleaning excess flux from the outside of the joint. Flushing practices are therefore inconsistent, and high rate flushing is not always possible.

Improper application of flux can be problematic because the residues are corrosive. Flux is applied to remove oxides on metallic surfaces prior to soldering, prevent the formation of oxides while the joint is heated, and to improve the wettability (spreading) of the solder (Humpston et al, 2004).

The corrosive property of flux stems from its content of activator chemical. The greater the concentration of the activator, the greater the ability of the flux to remove the oxides (Huang et al, 1995). Common activators in plumbing fluxes include zinc chloride and ammonium chloride (Triantafyllidou et al, 2012). Zinc chloride forms hydrochloric acid upon reacting with moisture at high temperatures (Humpston et al, 2004). Excessive residues containing chloride may also increase corrosion by increasing the conductivity of the water, as well as by preventing the formation of insoluble scales (Schock and Lytle, 2011).

While commonly used in plumbing practice, Humpston and Jacobson (2004) advise that fluxes containing ammonia should not be used on brass, because it can initiate intergranular corrosion. Ammonia-containing fluxes could also cause elevated metal concentrations, because the presence of ammonia may also prevent the development of protective films in both copper and lead pipes (Schock and Lytle, 2011).

The high organic content of flux could potentially influence corrosion, as NOM has been shown to increase lead release (Korshin et al, 2005; Korshin et al, 2000). It has also been demonstrated that NOM can prevent the formation of protective films in copper tubing (Arnold et al, 2012).

An ASTM International standard, B813, exists for WSFs. These fluxes are required to produce residues which are water flushable, they must not contain more 0.2% lead, and the flux must not be corrosive after the soldering (ASTM, 2010b). The *National Plumbing Code of Canada* (NRC, 2010) and the Copper Development Association (CDA, 2006) recommend using ASTM B813 Compliant fluxes, but there is no legal requirement to use these fluxes. As a result, non-compliant Traditional Petroleum Fluxes (TPF) are often used by plumbers.

In experiments by Raetz (2010), it was found that non-compliant TPFs can persist in a plumbing system through higher rate and duration flushing, but under stagnant conditions, the ASTM B813 compliant fluxes appeared to be more corrosive. While visually more corrosive, the ASTM B813 compliant fluxes were easily removed from the system following 30 minutes of high rate flushing (0.9 m/s); whereas TPF persisted in the system at flows greater than 2 m/s. One of the ASTM B813 compliant fluxes was then used in a follow-up study under flowing conditions, where it was found that the amount of flux did not affect metal concentrations (Triantafyllidou et al, 2012). This was due to the propensity of the compliant flux to flush under flowing conditions. The persistence of non-compliant fluxes may impact metal concentrations over longer term. The flows studied by Triantafyllidou et al (2012) ranged from 3.5 m/s to 0.5 m/s. In certain circumstances, such as in plumbing lines where the only available outlet is a low flow device such as fountains, the impacts of the flux could potentially be sustained for a much longer duration.

The goal of this research is to study the effects of two different fluxes on metal release of copper and brass fittings which are joined by lead free solder. An ASTM B813 compliant water soluble flux (WSF) and a TPF were applied under two different doses, and the soldered segments were exposed to two different flow rates. The persistence of the fluxes to remain in the experimental setup and the influence of the fluxes on metal release were investigated.

5.2 Materials and Methods

Description of Experimental Setup. This study was conducted using tap water supplied by JDKWSP, which was pumped from a continuous flow reservoir at predetermined intervals by peristaltic pumps. Between sampling, the pumps were timed to flush once every half hour for 15 seconds. During tests, the timers were disabled in order to allow the desired stagnation times. The influent water quality characteristics are summarized inTable 5.1. Metals concentrations are typically influenced by premise plumbing, so the metals concentrations presented are from initial screening results. Plant data was used for the other parameters.

Table 5.1: Treated water characteristics

Parameter	Treated Water Quality
pH	7.4
Turbidity (NTU)	< 0.1
Alkalinity (mg/L as $CaCO_3$)	20.5
Chloride (mg/L)	9.5
Sulfate (mg/L)	8.5
Copper (μg/L)	72
Lead (μg/L)	0.50
Zinc (μg/L)	80
Iron (μg/L)	11.2
TOC (mg/L)	1.8

This study was conducted at the bench scale and the experimental setup is shown in Figure 5.1. The numbers indicate the major components:

1. Covered reservoir with continuous flow-through ensuring fresh water
2. Timed power supply to control system flushing
3. Peristaltic pumps to supply the water through the system
4. The experimental apparatus
5. Sample location and outlets which drained into sink

The apparatus consisted of a half inch diameter brass union connected directly at each end to two, four inch length segments of half inch diameter copper tubing. The exact type of brass was unknown; however, the lead content was estimated at roughly 2.5% lead by mass, from heated digestions of the brass in concentrated acid. A summary of the estimated metallic composition of the brass is presented in Table 5.2.

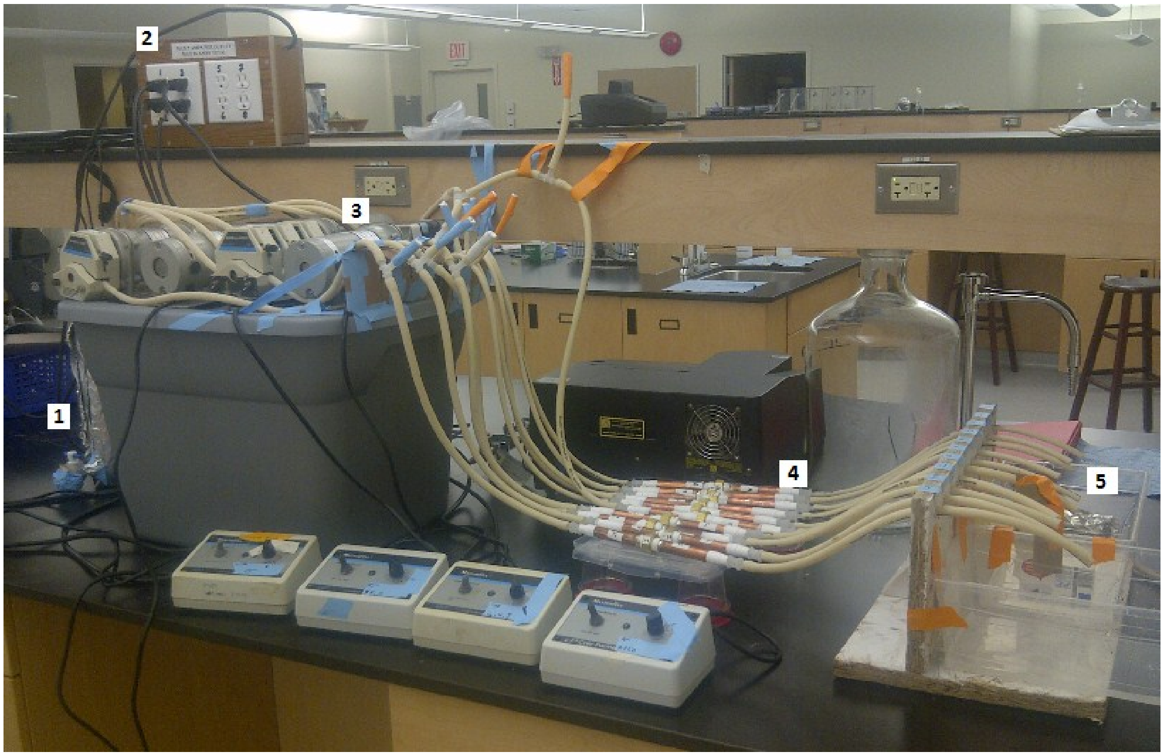

Figure 5.1: Photo of experimental setup

The plumbing segments were connected to the tubing using barbed reducer fittings, which were wrapped in Teflon plumbing tape to prevent water loss. Hydraulic conditions were controlled by placing the pipe segments below the pumps and tube outlets, and by installing Teflon t-fittings covered with filter paper to prevent suction head from developing. The experimental sections were always full of water, during stagnation and during flushing.

Table 5.2: Estimated metallic composition of the brass used in this experiment

Element	Average Composition (% w/w)	90% Confidence Interval
Copper	54	± 3.5
Zinc	39	± 1.9
Lead	2.3	± 0.072
Iron	1.1	± 0.93
Nickel	0.32	± 0.0097
Tin	0.81	± 0.10

In total there were 10 different setups which were tested at various conditions. The test was organized as a factorial experiment, where the factors included flux type, flux dose, and the flow rate. A summary of the test conditions is provided in Table 5.3. The soldering was performed according to ASTM B828, the Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube Fittings (ASTM, 2010a). A lead-free solder was used, which contains roughly 90% tin, less than 1% silver, and the remainder is copper. One week passed between the time the soldering was completed and the commencement of the experiment.

Table 5.3: Summary of experimental conditions

Identifier	Flux Dose	Flux Type	Flow Rate
A	High	TF	Low
B	Low		
C	High	WSF	
D	Low		
E	N/A	N/A	
F	N/A		
G	High	TF	High
H	Low		
I	High	WSF	
J	Low		

The two types of flux used were a TPF and an ASTM B813 compliant water soluble flux (WSF). The TPF is a highly active inorganic acid flux, which contains a suspension of a zinc chloride solution in petrolatum. According to the MSDS forms, it contains roughly 10 – 30% ZnCl by weight, and a slight amount of ammonium chloride, accounting for up to 5% by weight. The WSF is also an inorganic acid flux, containing a mixture of roughly 3 – 6% HCl and 1 – 3% ZnCl.

The fluxes were applied at two doses, where a low level represented a meticulously soldered joint with proper flux usage; the high level was one which represented a sloppy job with excessive application of flux. The two flow rates represented flows which could be expected from a drinking fountain, with a low flow of roughly 0.7 L/min (laminar flow) and a high flow of roughly 2.1 L/min (transitional turbulent) (Chadwick et al, 2004). Two apparatuses were not soldered, but instead contained copper tubing directly connected to the brass union and were tested at the two flow rates.

Experimental Methods. An initial flushing period was initiated prior to the operational period testing began. The first 100-mL volume flushed through the segments was collected for analysis, and flushing was continued for 40 minutes. While flushing, samples were collected after 20 and 40 minutes. After 40 minutes of flushing, the operational testing period was initiated.

Operational testing was conducted for a period of 13 weeks, and throughout this duration, samples were collected following various stagnation times, including eight hours, six hours, three hours, and one hour. Samples of 100 mL were collected in glass bottles which were hand washed with phosphate free detergent and rinsed with ultra-pure water (Milli-Q) following each test. Multiple tests following eight hours of stagnation were conducted each week to obtain weekly averages. For all other stagnation times, tests were conducted once per week. Between sample events, the system regularly flushed once every 30 minutes for a total of 15 seconds.

Analytical Methods. Samples were analyzed for metals by ICPMS (Thermo Fisher X Series 2 ICPMS) using Standard Method 3125. The detection limits of the various metals which were analyzed in this experiment are summarized in Table 5.4. Dissolved metals were analyzed biweekly in eight hour stagnation samples which were filtered through 0.45 μm polysulfone membrane filters.

Table 5.4: Method detection limits of metals by ICPMS

Metal	Detection Limit (μg/L)
Lead	0.4
Copper	0.7
Zinc	0.6
Iron	7
Aluminum	4
Tin	0.6

Phosphate, chloride, and sulfate ions were measured within two days of sample collection using a Metrohm 761 Compact IC with 788 Filtration Sample Processor. Total and dissolved organic carbon were analysed by a Shimadzu TOC-VCSH TOC Analyzer. Samples awaiting analysis for metals, organic carbon, or ions were kept at 4° C.

Temperature and pH measurements were obtained using an Accumet XL 50 pH meter with an Accumet combination pH electrode. Turbidity measurements were conducted using a Hach 2100N Turbidimeter. Free chlorine was measured using a Hach DR/4000 UV/VIS spectrophotometer using the DBP method.

SEM and EDS analysis was conducted on a brass and copper segment before and after the experiments were conducted. The samples were either mounted on SEM stubs using a glue gun and electrically connected to the stubs using silver paint, or placed in screw-tightened mounts. SEM and EDS analysis was performed using an Hitachi S-4700 FEG Scanning Electron Microscope, using an accelerating voltage of 20 kV and an emission current of 8.5 μA.

The composition of the brass components was estimated by dissolving segments in acid. A fragment of known mass was dissolved in a known volume of aqua regia (1:3 volume ratio of HNO_3:HCl), which was then heated to 85° C for roughly 30 minutes or until the entire fragment was dissolved. The sample was then analysed by ICPMS, which required several iterations of 10x serial dilutions in order to bring the elements to within the detection limits of the ICPMS.

Statistical Analysis. Repeats on the eight hour stagnation samples were collected each week to determine the 90% confidence interval for the metal concentrations. The experiment was conducted as a factorial experiment with three factors. To determine the factors which significantly affected metals release, analysis of variance (ANOVA) was performed, using Yates' Algorithm with a 95% level of significance. This was performed for various metals concentrations at various weeks, to determine the duration for which the effects were present.

5.3 Results and Discussion

Testing was conducted throughout 13 weeks to determine the effects of plumbing flux with regards to metals release from segments consisting of a brass union soldered to copper tubing using lead free solder. The estimated metallic composition of the brass, as estimated by acid digestion and ICP-MS analysis, is listed in Table 5.2. Segments of both the brass and copper were analysed by SEM and EDS prior to the commencement of the experiment, and are shown in Figure 5.2. Both surfaces were relatively smooth, with some visible imperfections. EDS area analyses of the materials provided an approximation of the ratios at which the various elements were present along the interior surface of the pipe and fitting. The surface of the brass contained roughly 55% copper, nearly 30% zinc, and the remainder was comprised of tin, nickel, iron, and aluminum. The copper surface was comprised of roughly 80% copper, around 15% carbon, and trace amounts of oxygen and aluminum.

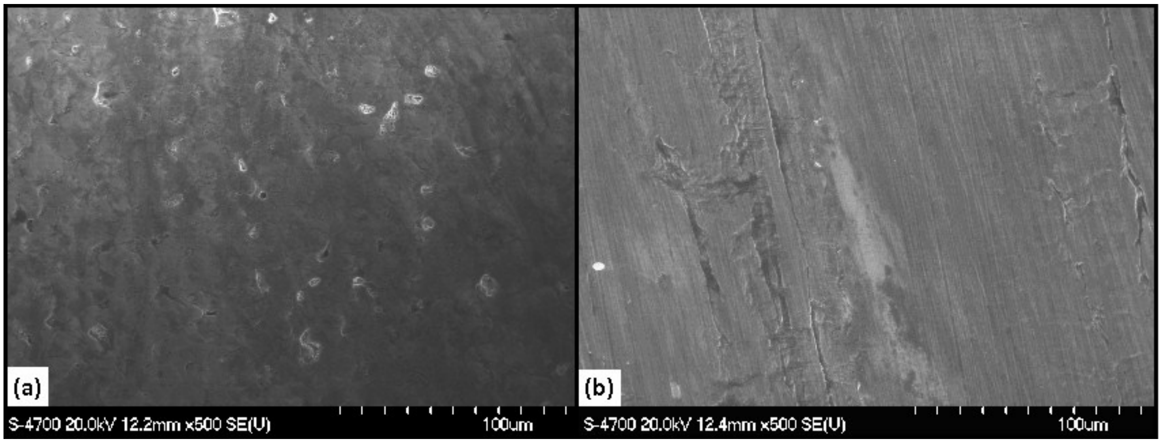

Figure 5.2: SEM images of the interior surface of (a) the brass fitting and (b) the copper pipe prior to experiment

The segments and conditions are summarized in Table 5.3. It was elected that the no-flux condition (segments E and F) would not contain a soldered joint, but would instead contain a direct connection between the brass union and the copper tubing. Segments E and F were originally considered to have soldered joints without the flux; however, this option would have had its own drawbacks. Oxides, which would have been present before the soldering was performed as well as those which would have formed while the joint was exposed to the high soldering temperatures, would have impeded the spreading of the solder, and would have resulted in a deficient joint (Humpston et al, 2004). This poor joint could therefore have been expected to create an abundance of particles which would have affected results, or possibly created oxides with differing solubility characteristics than the oxides which formed under the normal exposure to the test water.

Flushing Period. The experiment was initiated with a 40 minute flushing period, which was directly followed by the operational period, where the first overnight stagnation period began immediately after the flushing was completed. Metals samples were collected during the initial flush, and after 20 and 40 minutes of flushing, and the lead and tin concentrations from these samples are presented in Figure 5.3.

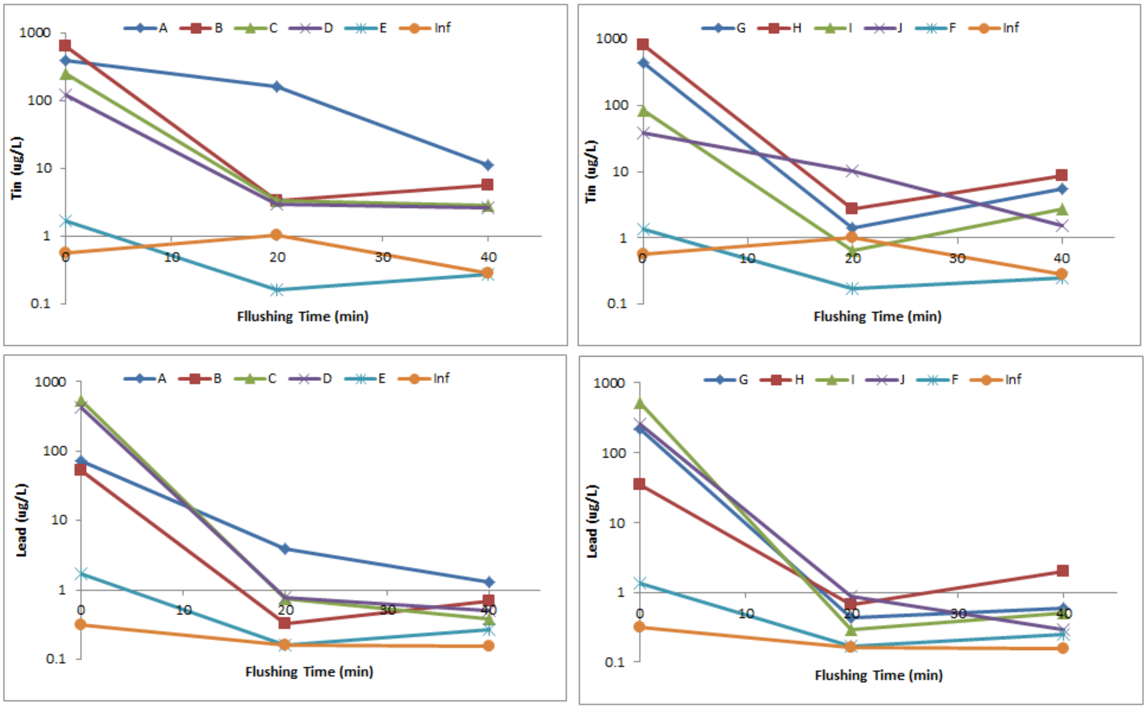

Figure 5.3: Tin and Lead concentrations during the flushing period

The flushing period was implemented to represent a minimal flushing effort which could be expected to be performed during routine soldering operations by plumbers in the field. Numerous maintenance staff plumbers from Dalhousie University were consulted to obtain an estimate of typical flushing protocols implemented in practice. The duration and flow rates used for flushing varied between the various employees. Although flushing was generally acknowledged as an important step following a soldering operation, it was not done consistently between the staff, and the flushing practices tended to be minimal, often running the outlet for less than 30 seconds. This is in definite contrast to the flushing recommendations for new plumbing, as suggested by Case (2011), at 30 minutes of flushing at a high velocity of 3.6 feet per second. While all segments were flushed for 40 minutes, half were flushed at the low flow rate, and the other half were flushed at the high flow rate selected for this study to mimic flow rates expected from drinking water fountains. The flushing employed in this study was selected to be representative of a flushing event which might be expected to be implemented in practice, but which would also be significantly lower than the recommended flushing suggested by Case (2011).

The TPF caused high tin concentrations in the initial sample; however, the tin levels dropped after 20 minutes of flushing in all samples except the high dose of TPF under the low flow condition (A). The WSF appeared to be more corrosive towards lead, as shown by the first draw concentrations, but following only 20 minutes of flushing, the only high lead levels appear to be from the same high dose of TPF, under low flow condition which caused the elevated tin. The TPF also appeared to be more corrosive towards copper in the first draw sample as well (not shown). High zinc concentrations were found in the first draw samples from all segments, but it is difficult to determine which flux was more corrosive towards the zinc in the brass, as a significant amount of the zinc levels likely originated from the fluxes. The only condition with elevated zinc levels after 20 minutes of flushing was once again condition A (not shown), which produced zinc levels greater than 12x the influent zinc concentration. Even after 40 minutes of flushing, the zinc levels in segment A were still more than double the influent concentration. The flushing period was estimated to result in flushed volumes of 24 L and 80 L for the low flow rate and high flow rate conditions respectively.

Operational Period. During the first few sample events, metals concentrations were rather unstable, but after the first week, metals levels began to stabilize on a week by week basis. In figures presented below, the first draw sample collected during the flushing period is always referred to as ‘Week 0’. For all subsequent weeks, each data point represents the average of either three or four measurements collected throughout the given week.

Effect of Flow Rate. Lead concentrations from all segments were elevated in the first few eight hour stagnation samples collected during the operational period. Lead levels decreased abruptly in all samples by the second week (Figure 5.4). By examining the initial sampling events, it was estimated that the lead levels stabilized to consistently low levels following exposure to roughly 40 L and 140 L of water for the low and high flow conditions, respectively. The zinc and copper levels also stabilized following roughly the same duration and flushed volumes. The low volume required to reduce the lead concentrations was relatively unexpected, because the high rate flushing suggested by Case (2011) equates to volumes of nearly 250 L for half inch pipe, such as was used in this study.

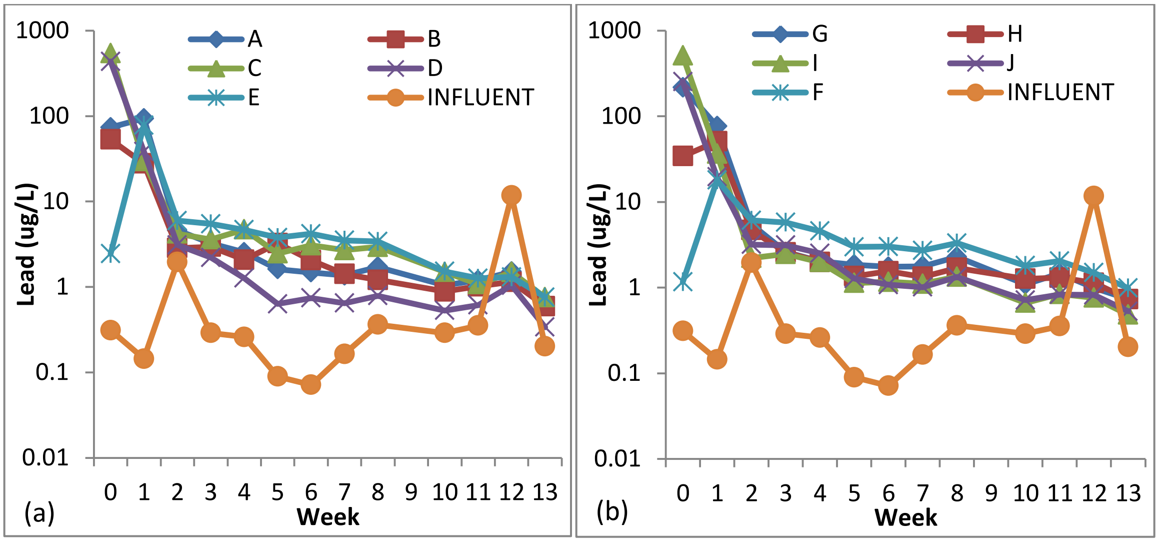

Figure 5.4: Lead concentrations under (a) low flow conditions, (b) high flow conditions

Tin levels from segments which were soldered using the TPF appeared to be influenced by the flux for several weeks, as shown in Figure 5.5. For the first draw flush (week zero) and week one, all the soldered segments had elevated tin levels compared to the influent and no-flux conditions. The WSF exhibited the same short term effects on tin release as was evidenced with lead levels. For a given week, there was never a statistical difference in tin levels under high flow compared to low flow conditions. However, the flow rate had an impact on the duration of elevated tin levels for the components which were assembled with the TPF. The tin levels for the segments under low flow condition (A and B) remained elevated, above concentrations of 15 μg/L through the fifth week; whereas, the segments under the high flow, G and H, had decreased below 15 μg/L by the fourth week.

The effects of flow rate on lead concentration throughout the experiment were quite minimal, and were only found to be statistically significant (95% confidence level) during weeks two and three. In week two, the combined effect of TPF under the high flow condition was found to slightly increase the lead levels. During the third week, high flux dose and high flow rate were shown to slightly decrease lead levels. During both weeks, the magnitude of these effects was quite small. The elevated lead associated with elevated flow rates during week two was potentially a result of greater mobilization of particles, as found in other studies (Cartier et al, 2012a).

Both flow rates used in this study were low, but the difference was great enough to have a brief impact on metal concentrations and on the duration of elevated tin. This was not surprising, as other researchers have found that even a laminar flow rate can increase dissolved and particulate lead levels compared to stagnant conditions (Xie and Giammar, 2011). While high rate flushing is ideal, low flow flushing is useful when it is the only option, such as in cases of maintenance plumbing where low flow devices are the only available outlet.

Effect of Flux Type and Dose. Flux type and flux dose were significant factors affecting lead levels during the first flush and the first two weeks of the operational period. Interestingly, for the initial first draw sample, the WSF was found to cause elevated lead levels, whereas for the weeks one and two the TPF was a cause of high lead. This suggests that the water soluble flux is corrosive but that it readily flushes, as implied given its ASTM certification and similarly to what was found in other studies (Triantafyllidou et al, 2012; ASTM, 2010b). The higher flux dose was found to increase lead levels in the first draw sample and through week one.

From the second week through the remainder of the study, the highest lead levels were found in samples E and F, where the apparatuses consisted of the brass segments directly connected to the copper tubing without solder or soldering flux (Figure 5.4). This does not suggest that the plumbing flux had a decreasing effect on the lead levels; instead, the tin from the solder was likely sacrificial to the other metals present in the brass and copper pipe segments, as noted by the elevated tin levels in the soldered components, particularly with the TPF segments, as shown in Figure 5.5. The effects of the two fluxes on lead release were minor and brief. This was somewhat unexpected, particularly with respect to the TPF, as other studies have shown them to persist within plumbing, even at flows greater than 2 m/s (Raetz, 2010). The short term effects of the WSF were not as surprising, as flushing likely removed the corrosive residues (Triantafyllidou et al, 2012).

The relatively small effects of the fluxes on lead levels could result from the somewhat small source of available lead in this experiment, as the only source was from the brass which had a lead content of roughly 2.5% and held a volume of only 2 mL. Similarly, copper loss was not greatly influenced by flux type or dose, as all flux conditions had similar copper levels by week 2 (appendix). Unlike lead, copper was in abundant supply, between the copper tubing and the high copper content of the brass. The low levels of copper and lead were likely attributed to the tin from the solder acting as a sacrificial metal, as tin is lower in the electrode potential series (Petrucci et al, 2002). Zinc, which is likely to anodic to tin based on the electrode potential series, appeared to be have slightly elevated levels in the segments with the TPF; however, this was only statistically significant during week one.

While the tin may have provided cathodic protection to the copper tubing at the joint, it was still somewhat surprising that the fluxes did not seem to have such a strong effect on copper levels in the water, particularly with the TPF, which was visually shown to run a significant distance along the copper tubing, away from the joint (Figure 5.9 (a) and (b)). By visual observation (Figure 5.9), it seemed as though the TPF was more aggressive than the WSF towards the copper corrosion; however, the copper concentrations were not in agreement with this theory. Flux residues have been associated with initiation of copper pitting (Myers and Cohen, 1994); however, the causes of pitting are complex and its initiation by plumbing flux is currently unproven in laboratory experiments (Farooqi et al, 2009). Chloride ions, which were present in both fluxes, are aggressive to copper corrosion in the short term (Edwards et al, 1994). The chloride levels in this study began at very high concentrations, particularly in segment A, but the concentrations decreased rapidly by the third day (Appendix C).

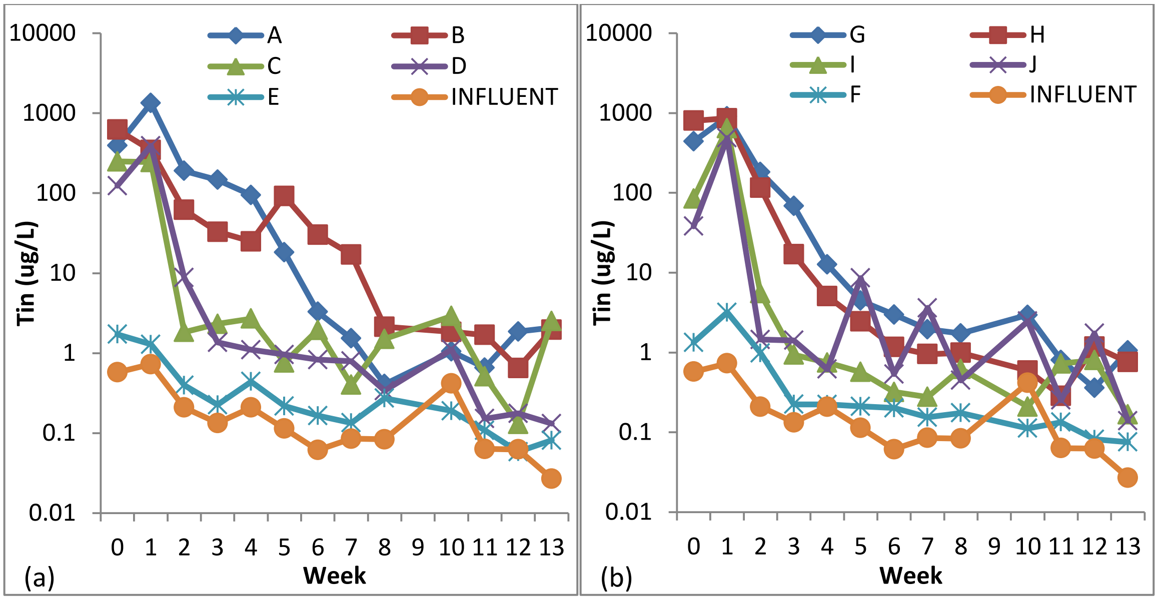

Figure 5.5: Tin concentrations under (a) low flow and (b) high flow conditions

As noted above, the TPF segments were found to produce elevated tin concentrations for several weeks, especially under the low flow conditions Figure 5.5. The amount of flux did not seem to impact tin levels. In fact, the lower dose of the TPF under the low flow condition (B) sustained a longer duration of more elevated tin levels than the high dose (A). Samples which were soldered with the TPF (A, B, G, and H), produced elevated tin levels (statistically significant 95% confidence) during weeks two and three. Tin levels from WSF segments decreased by week two, and the weekly average concentrations from these segments were not statistically different from the no flux conditions (E and F), as determined by paired t-testing at the 95% confidence level. While ASTM compliant fluxes may be more corrosive in the short term, as evidenced by dump and fill testing by other researchers, they are readily flushed and their effects are short lived, even under low flow conditions (Triantafyllidou et al, 2012). The persistency of the TPFs suggests that their use should be terminated. This might be of particular importance in cases where larger sources of lead are present, such as with larger brass devices, plumbing which involves a series of several brass devices, or from brasses with high lead contents.

The high tin levels from the TPF segments during the first few weeks were comprised mainly of particulate tin Figure 5.6. This is unsurprising, as tin is highly insoluble under the oxidizing conditions typically encountered in drinking water systems (Lytle et al, 1993). In plumbing systems where lead-free solders are used, elevated concentration of tin particles is not a serious health risk, because tin is typically excreted from the body fairly rapidly with very little entering the bloodstream (ATSDR, 2005); however, in leaded solders, these particulates would likely contribute to lead levels. This was the case in a study by other researchers, where erosion of leaded-solder was found to cause particularly high spikes in lead levels (Lytle et al, 1993).

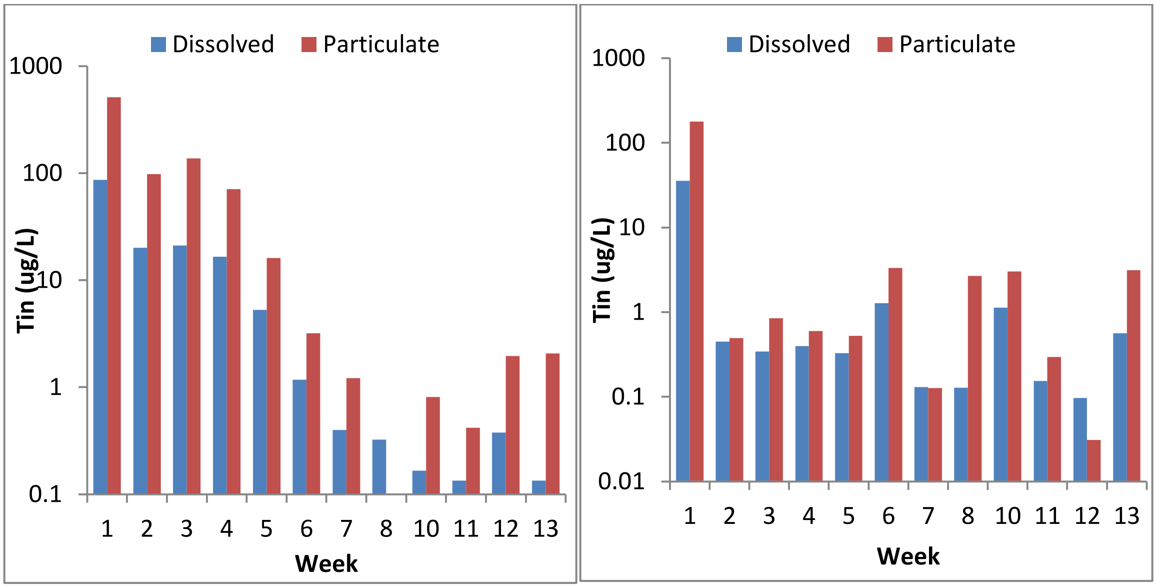

Figure 5.6: Dissolved and particulate tin concentrations in samples from (a) segment A and (b) segment C

The combined effect of flux dose and flux type had a statistically significant effect on tin levels in week two, where the high dose of the TPF increased tin concentrations. Interestingly, the individual effects of flux dose and flow rate were never found to be significant factors on tin levels. The insignificant effects of the flux dose were unexpected, as excessive flux applied during soldering is a major source of contamination in the manufacturing of PCBAs as well as has been associated with inducing corrosion in copper plumbing (Jellesen et al, 2010; Myers and Cohen, 1994).

Figure 5.7 draws emphasis to the minimal impact of flow on tin release compared to the effects of the flux type. Shown in the figure are the four segments which contained the high dose of the respective flux: A is the high dose TPF under low flow; G is high dose TPF under high flow; C is high dose WSF under low flow; and I is the high dose WSF under high flow. It is shown that the WSF conditions were similar, regardless of flow, and that the TPF conditions were also quite similar, although the tin levels dropped off slightly earlier under the higher flow, compared to the lower flow.

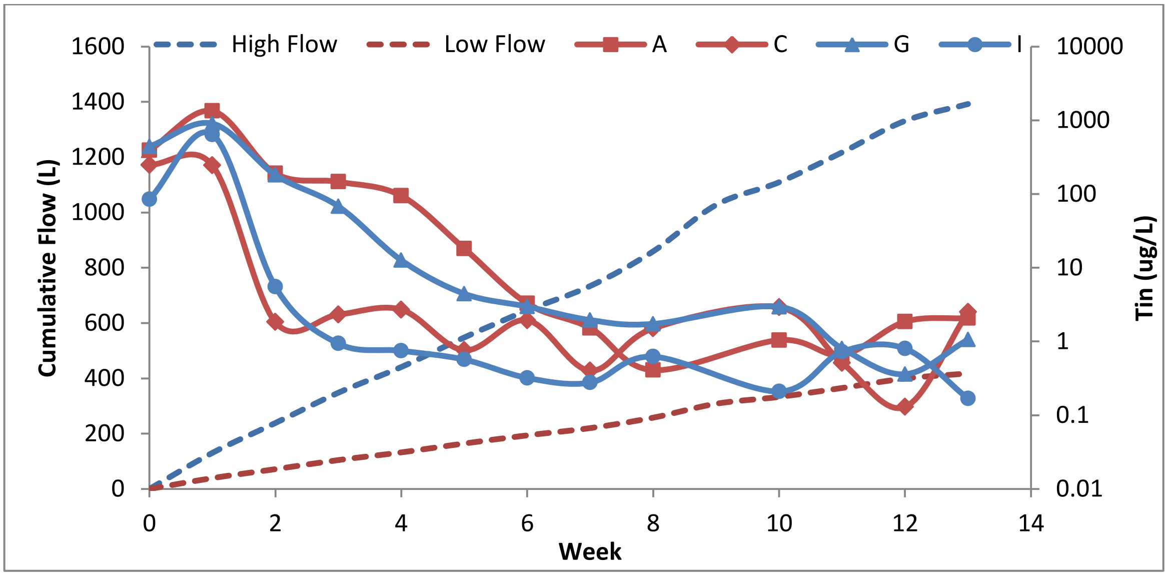

Figure 5.7: Estimated flows throughout the duration of the study and tin levels from the high flux dose segments

Effect of Stagnation Time. Samples were collected following various stagnation times to determine how quickly metals concentrations increased in the systems. Samples were collected each week following one, three, six, and eight hours of stagnation. Minimum concentrations of any given metal typically came after one hour of stagnation and increased continually until reaching a maximum following eight hours of stagnation. It is unlikely that the absolute maximum concentrations were reached following only eight hours, as previous studies have shown copper and lead concentrations to increase for 24 hours or longer (Lytle and Schock, 2000). Although not anticipated as the duration for maximum concentrations, eight hours was chosen as the greatest duration of stagnation because of its common use in field studies and its practicality for obtaining a large amount of samples in a limited time.

The effects of stagnation time were the most consistent and uniform with copper levels. For any given week, the concentrations were lowest following one hour stagnation and increased continually reaching a maximum following the eight hour stagnation. However, from week to week, the copper concentrations hardly changed for any given system.

Lead and tin concentrations also followed a similar stagnation time trend, but to a less pronounced extent, and concentrations were often slightly more sporadic. Figure 5.8 shows tin concentrations from segments A and C, which provide an accurate representation of the other components under the TPF and WSF, respectively. For both flux conditions, lead and tin concentrations did not always increase with the increasing stagnation time, and from time to time, the greatest concentration for a given week was found after the lowest stagnation times.

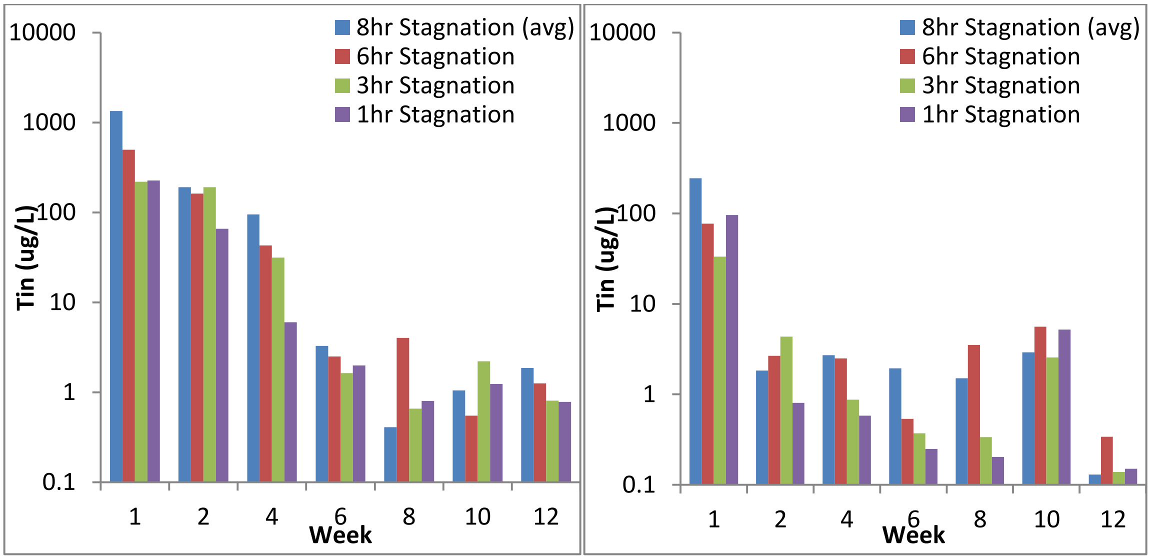

Figure 5.8: Tin concentrations as a function of time at various weeks of sampling for (a) segment A and (b) segment C

Visual Analysis. The rapid decrease of chloride concentrations seemed to indicate that the fluxes were no longer present, or at least unlikely to affect metals concentrations; however, tin levels remained high for several subsequent weeks, and even three full months after the chloride concentrations had decreased, high levels of chloride were found by EDS measurements of corroded areas from the TPF segments. Furthermore, flux residues were identifiable through visual inspection of the TPF segments when they were cut longitudinally (Figure 5.9). The TPF samples, A and B, had visible flux runs, also known as flux ghosts. These are shown in Figure 5.9 as the sections where the metal appears to be more corroded, as evidenced by the blue-green pools of copper oxides, and the particles from cutting the segments are still stuck in the flux paste. It was surprising that the TPF paste was able to remain fixed to the copper following over three months of regular flushing. The flux ghosts were not evident in the WSF samples, C and D; however, the higher dose of the water soluble flux contained several dark areas where the copper was a very dark blue or black.

EDS analysis of selected spots on the copper segments showed high quantities of chlorine (often greater than 5% by mass), likely in the form of chloride, in the blue-green corroded areas of the segments soldered with the TPF. Segment A appears to have undergone significant copper corrosion, which is unsurprising because of the high chloride content of the TPF, which is aggressive to copper corrosion in the short term (Edwards et al, 1994). At the selected spots in the highly corroded areas on the WSF segments, chlorine accounted for typically less than 0.5% by mass. Sulfur was not found at any of the spots where EDS analyses were performed. Interestingly, the high mass of chlorine on scales on segments A and B were only present on the copper surfaces, and not on the brass surfaces. In segment E, where flux was not applied, there was no significant visual evidence of major copper corrosion.

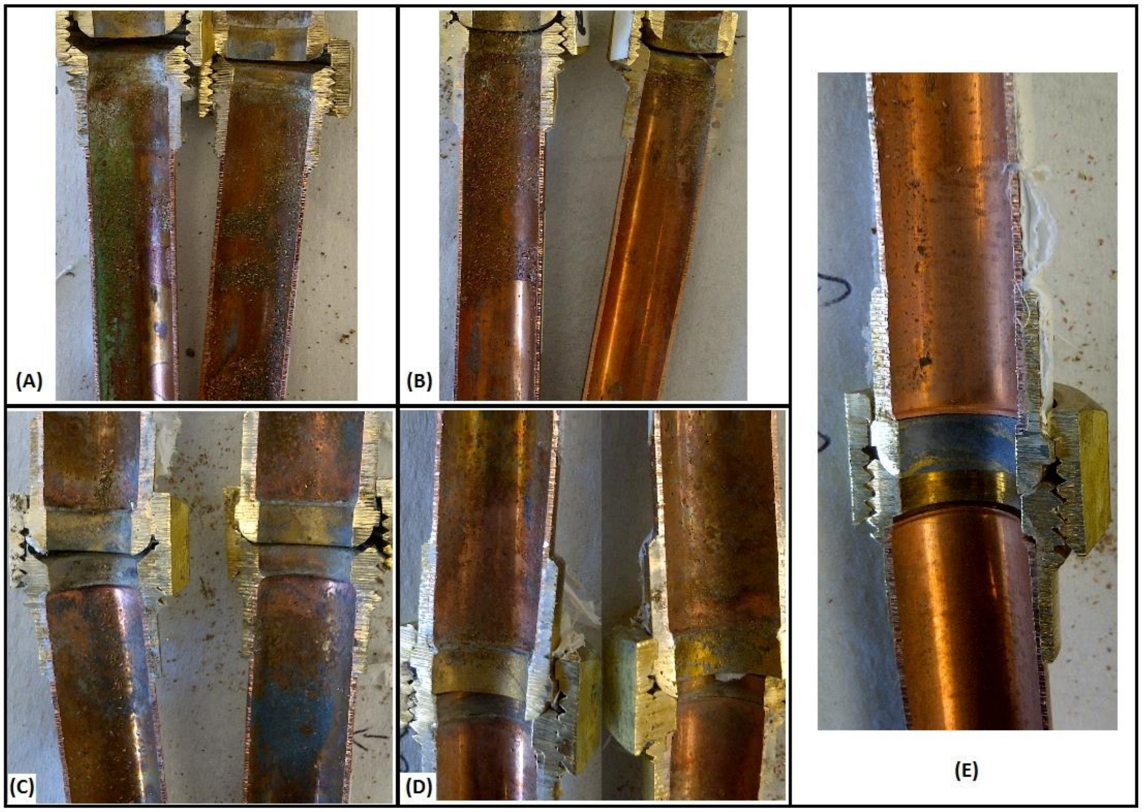

Figure 5.9: Segments from low flow condition (A-E) cut longitudinally following the experiment

It is difficult to deduce whether pitting would occur as a result of excessive TPF, had the experiment run for several more months. The TPF supplied a high amount of chloride ions, which may have been sufficient to initiate the pitting corrosion, as chloride ions are often implicated in pitting corrosion in one way or another (Lytle and Schock, 2008). However, sulfur was not found in any significant amounts in any of the EDS measurements, and sulfate has been identified as a significant factor in initiation and propagation of copper pitting (Edwards et al, 1994). While it is uncertain whether TPF could have played a role in copper pitting corrosion, the visual inspection clearly identifies the role TPF has in accelerating copper corrosion.

Selected SEM images from the brass segments under the low flow conditions are shown in Figure 5.10 and images from the copper segments are shown in Figure 5.11. As shown in Figure 5.9, a large amount of preparation artifacts were present in the form of shavings from the cutting process which were often lodged in the soft areas of flux residue. Although polishing and finishing are important steps to ensure accurate analysis of the corrosion scales (Nadagouda et al, 2011), it was not performed in this study, as it was important to not disturb the flux residues to ensure they were included in the analysis.

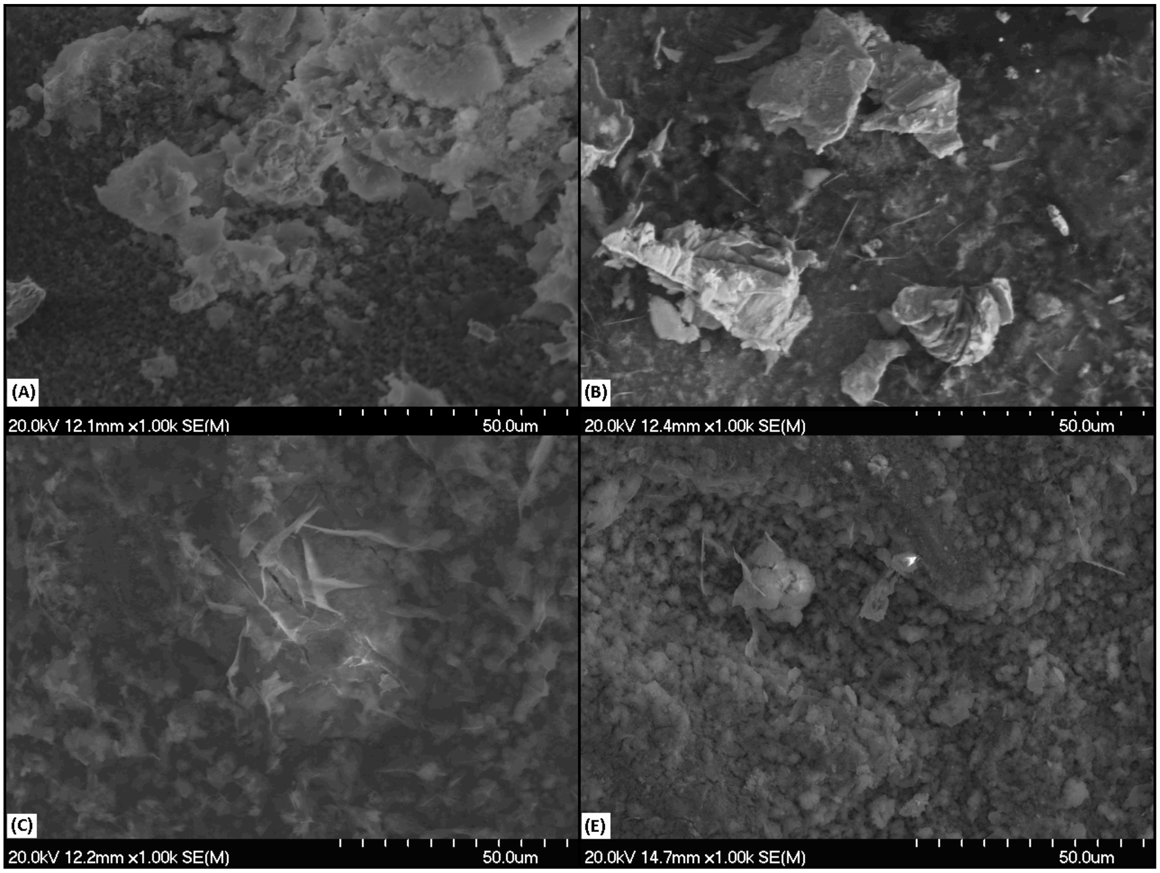

Figure 5.10: SEM images of the exposed surfaces from brass segments A, B, C, and E following the experiment

SEM analysis showed a significant change in the brass segments over the course of the experiment. Initially, the segments were quite smooth (Figure 5.2), but by the end, the segments contained either jagged or dendritic structures Figure 5.10. Summaries of the EDS analyses of the brass and copper segments are provided in Table 5.5 and Table 5.6, respectively.

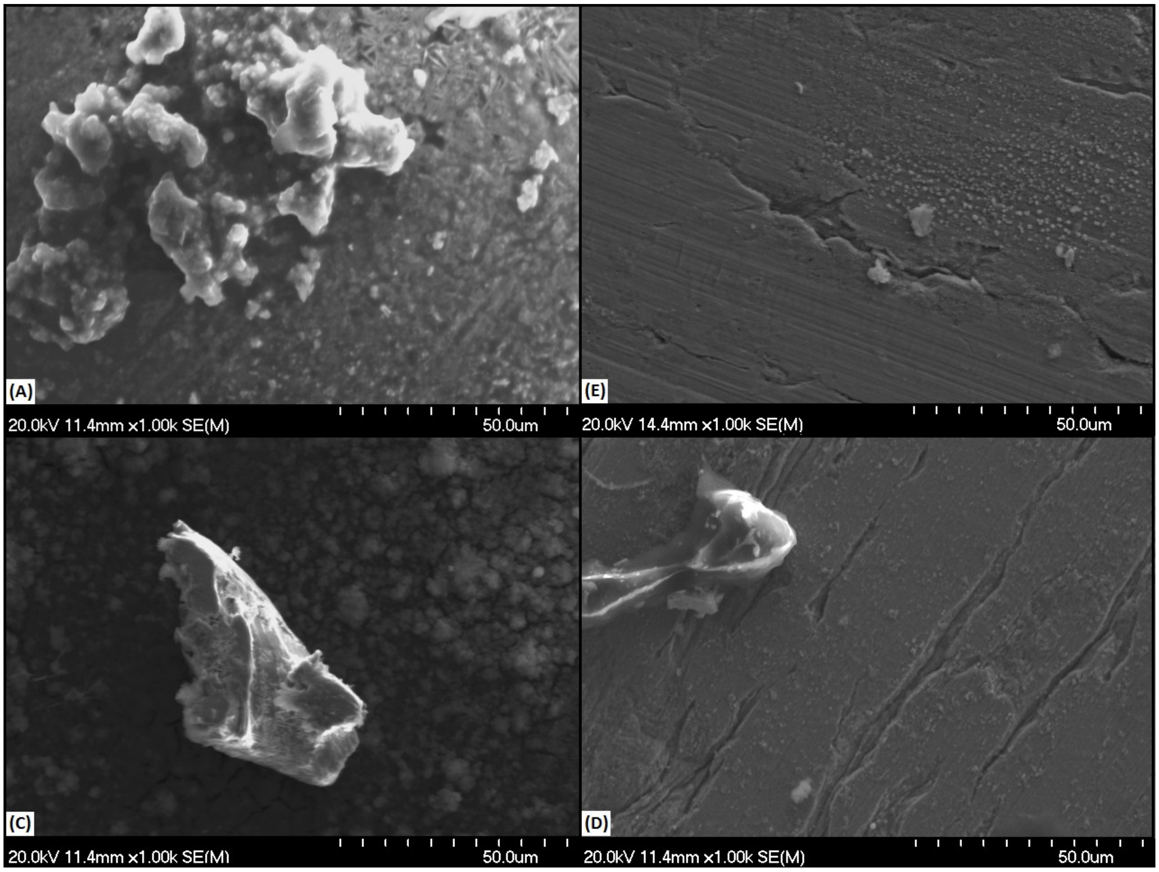

Figure 5.11: SEM images of exposed copper surfaces from segments A, E, C, and D

Sample A was visibly quite corroded in both the copper and the brass, and provided an interesting specimen for SEM/EDS analysis. Several areas were found to have very high tin contents (as high as 60% by mass at one spot). This may have occurred because of the increased wetting of the joint resulting from the excess flux.

Table 5.5: Elemental composition results of EDS spot measurements collected from select areas of brass segments from the apparatuses under low flow conditions

Sample	Spot	C	O	Al	P	Cl	Fe	Cu	Zn	Sn	Pb
A	1	5.46	18.09	0.4				5.41	2.85	66.96	
	2	36.92	26.66	0.27	0.52			3.55	29.42	1.07	1.48
	3	20.65	33.41	0.36	0.52			4.95	10.94	25.55	1.74
	4	32.7	31.65	0.43	0.46		0.14	2.61	5.9	17.28	6.42
B	1	15.93	1.32	0.69			0.42	69.49	7.93	4.22	
	2	19.85	2.4	0.65			0.46	37.42	35.68		
	3	13.85	1.43	0.94		0.17	0.43	78.26	2.34	1.62	0.97
	4	10.61	1.27	1.54			2.24	75.93	2.2		6.21
C	1	7.64	25.47	1.36	2.64		1.93	21.36	7.81		30.75
	2	5.94	27.35	1.64	3.41	0.33	2.37	37.18	11.95		8.11
	3	9.04	27.41	1.37	2.46	0.31	1.87	30.75	9.99		15.45
	4	6.96	22.21	1.39	2.6		1.37	39.73	9.76	0.69	14
D	1	8.74	21.91	1.21	1.89		0.63	27.56	24.29	3.76	10
	2	49.87	21.39	0.51	0.91	0.24	0.16	9.71	11.7	1.66	3.63
	3	4.36	11.51	1.23	2.21		0.65	45.62	22.45	5.12	6.84
	4	10.95	30.73	1.62	2.89	0.23	0.83	11.33	26.26	3.42	11.74
E	1	8.34	20.36	3.66	4.85		1.94	30.48	9.48		20.66
	2	11.79	24.42	4.04	3.55		1.61	15.16	6.7		32.19
	3	10.2	22.93	3.64	5.46		2.26	26.86	9.99		18.37
	4	15.61	29.54	6.53	3.6		1.86	15.63	9.25		16.47

Table 5.6: Elemental composition results of EDS spot measurements collected from select areas of copper segments from the apparatuses under low flow conditions

Sample	Spot	C	O	Al	P	Cl	Fe	Cu	Zn	Sn	Pb
A	1	39.96	8.31	0.14	0.22	6.9		37.72	4.98	1.28	
	2	69.21	13.81		0.22	1.01		10.21	5.4		
	3	48.79	6.71		0.16	8.56		30.35	5.05		
	4		27.87	0.9	0.86	11.47		30.03	23.43	3.15	
B	1	64.57	1.29	0.18				18.92	14.28	0.77	
	2	59.63	2.04					38.33			
	3	47	16.1			6.81		21.98	7.59		
	4		48.87	1.32		4.57	0.61	8.02	1.93		
C	1	2.24	2.39	0.2				89.93	2.13		3.11
	2	11.78	39.06	1.58	5.84	0.28		37.35	2.58		1.38
	3	5.16	1.62	0.44			0.45	50.01	34.62		4.52
D	1	14.2	5.91			0.45		79.44			
	2	67.86	13.45	0.13		0.23	0.09	17.96		0.29	
E	1	6.99	2.1					90.91			
	2	17.82	21.08	0.31	0.4	0.79	1.21	51.18	7.21		
	3	8.27	2.99	0.47				54.83	33.44		
	4	6.9	2.23					90.87			

SEM images of the WSF segments contained no visual similarities for the copper pieces. The copper in the high dose WSF condition, C, contained a much greater amount of corrosion product, which was present in the form of a very rough and uneven, yet rounded and not-jagged surface. The low dose WSD condition, sample D, contained a much larger area of exposed copper, with the occasional large particle (Figure 5.11d). The SEM images from the brass segment from sample C (Figure 5.10c) were very similar to those of segment D (Appendix C). The corrosion products appeared to be lightly scattered across the corroded surface. The EDS analysis of the brass segments from the WSF conditions revealed high lead content on the exposed surface (Table 5.7). This may have either resulted from selective corrosion of the other elements in the brass, such as zinc or tin, which would have left large pockets of lead; or perhaps, the corroded lead formed an insoluble corrosion scale which was measured.

The segment which did not have any solder applied, sample E, underwent significant corrosion to the brass surface, but very little corrosion took place on the copper tubing. This was expected, as the copper was expected to be cathodic to the brass, which contains more electronegative materials such as tin, lead, and zinc.

5.4 Conclusions

The impact of plumbing flux on metal concentrations was relatively short in duration, lasting only a week for most metals, with the exception of tin. Lead levels were found to stabilize under all flux conditions following roughly 40 L of flushing. Flux dose and flow rate had a slight impact on metal concentrations, but this was only for a few weeks. Flux type was the main factor contributing to the elevated metals. The TPF was much more resistant to flushing than the WSF, as it caused elevated tin levels for several weeks and a tacky flux deposition in the copper pipe remained even three months after the start of the experiment. The high amount of chloride from the flux was aggressive towards the copper corrosion, but it is unclear if this would have led to copper pitting corrosion. The large amounts of tin released are not problematic from a health perspective as long as lead-free solders are used; if however, lead solders were used illegally, high lead concentrations could be expected.

Chapter 6: Conclusion

6.1 Summary and Conclusions

Three rounds of a lead monitoring program were performed according to the first tier testing protocol outlined in the Health Canada Guidance on Controlling Corrosion in Drinking Water Distribution Systems for the two exposure patterns (Health Canada, 2009). The lead action level for residential testing was exceeded in the third round, which was conducted in the winter. Lead concentrations were higher in the winter monitoring of non-residential buildings as well. This was unexpected, as lead concentrations are typically higher in the summer. Health Canada (2009) even recommends that utilities conduct their annual monitoring during the summer to account for the worst case lead levels. The seasonal lead variation was likely caused by seasonal fluctuations in aluminum residuals in the water leaving the plant.

High lead was found at faucets which seemed to receive infrequent usage, as well as at several drinking fountains which were all of similar vintage and located in the same three buildings. Frequency of use, age, and outlet manufacturer were factors which were associated with elevated lead levels.

Follow-up studies were conducted at several fountains to determine the source of elevated lead levels. These fountains typically contained several leaded components and received infrequent use. Fountains with leaded components which received high, regular usage had often provided samples with low lead levels.

Drinking fountains which were banned and recalled in the US for potentially containing lead lined cooling tanks were found at eight locations throughout the study area. It was determined that three of the eight likely contained the lined cooling tanks. High lead levels were present in samples collected from these fountains, even at sites with frequent usage. Low-use sites with the lead lined tank produced the highest lead levels in this study. Fountains suspected of containing lead lined tanks were removed and replaced, and the lead levels were significantly reduced.

The impact of plumbing flux on metal concentrations was relatively short in duration, lasting only a week for most metals, with the exception of tin. Lead levels were found to stabilize under all flux conditions following roughly 40 L of flushing. Flux type was the main factor contributing to the elevated metals. The TPF was much more resistant to flushing than the WSF, as it caused elevated tin levels for several weeks and a tacky flux deposition in the copper pipe remained even three months after the start of the experiment. The high amount of chloride from the flux was aggressive towards the copper corrosion, but it is unclear if this would have led to copper pitting corrosion. The large amounts of tin released are not problematic from a health perspective as long as lead free solders are used; if however, lead solders were used illegally, high lead concentrations could be expected.

6.2 Recommendations

Further research should be conducted to investigate the relationship between aluminum concentrations and lead release. If further research demonstrates that the seasonal trend in lead concentrations results from the seasonal trend in residual aluminum concentration, then methods to reduce residual aluminum concentrations should be investigated.

Further studies should also be conducted to optimize corrosion inhibitor performance. This research found very low phosphate content in the corrosion scales which were examined from various fountain components. Changing the dose, particularly during the winter, might help reduce lead concentrations.

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Appendix A – Lead Monitoring Program

Table A.1: Residential monitoring data – October 2010

			Oct-10					
Building	Faucet manufacturer		pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp ('C)	Lead (µg/L)	Copper (µg/L)
C3	Valley	1st Draw		0.07	0.3		0.3	83
		Flush					0.3	23
C4	Waltec	1st Draw		0.07	0.73		7.3	98
		Flush					4.5	18
B1	No Name	1st Draw		0.1	0.68		15.3	77
		Flush					10.6	11
D1	Aristaline	1st Draw		0.09	0.74		1.0	65
		Flush					0.3	11
A1	Moen	1st Draw		0.1	0.73		3.1	42
		Flush					1.0	8
D3	Moen	1st Draw		0.15	0.73		3.3	65
		Flush					2.5	25
B2	Moen	1st Draw		0.07	0.67		5.1	21
		Flush					2.7	5
A2	Aristaline sink	1st Draw		0.14	0.71		0.5	85
		Flush					0.3	7
D2	Steel Queen sink	1st Draw		0.09	0.75		4.5	187
		Flush					3.3	21
C6	Waltec	1st Draw	7.41	0.11	0.7		4.6	145
		Flush					0.3	23
A5	Waltec	1st Draw	7.4	0.09	0.51		31.3	667
		Flush					4.5	176
A6	Waltec	1st Draw	7.47	0.44	0.76		3.3	71
		Flush					1.5	11
C7	MKE Sink (unnamed)	1st Draw	7.4	0.12	0.76		0.8	273
		Flush					0.3	27
A3	Moen (clogged aerator)	1st Draw	7.55	0.17	0.5		8.0	311
		Flush					9.2	45
A4	Unnamed	1st Draw	7.66	0.09	0.73		3.5	177
		Flush					0.3	27
C5	Unnamed	1st Draw	7.81	0.07	0.75		5.5	209
		Flush					0.5	31
D5	2nd floor kitchenette	1st Draw					5.3	223
		Flush	7.4	0.38	0.04	17.3		
D6	main floor kitchen, white	1st Draw					1.1	28
		Flush	7.93	0.27	0.35	14.1		
C1	Waltec	1st Draw		0.12	0.59		3.9	512
		Flush					0.6	61
C2	Crane	1st Draw		0.11	0.61		3.5	167
		Flush					0.7	38
C8	Moen	1st Draw	7.62	0.07	0.57		12.3	247
		Flush					1.1	21
C15	Waltec 10	1st Draw	7.59	0.14	0.65		2.8	29
		Flush					0.5	22
C16	Waltec	1st Draw	7.44	0.17	0.69		5.5	94
		Flush					0.5	15
C17	Waltec	1st Draw	7.54	0.12	0.45		2.9	315
		Flush					0.3	97
C12	Emco	1st Draw	7.44	0.08	0.74		0.3	19
		Flush					0.3	90
C13	Waltec	1st Draw	7.81	0.14	0.8		3.6	60
		Flush					1.9	12
C14		1st Draw	8.9	0.2	0.73		0.3	5
		Flush					0.3	28
C18	Waltec	1st Draw	7.57	0.11	0.7		1.2	95
		Flush					0.3	13
D4	Waltec	1st Draw	7.93	0.07	0.61		1.3	49
		Flush					0.6	17
D7		1st Draw	7.37	2.13	0.29	19.8	15.3	906
		Flush						
C9	Waltec (old one)	1st Draw	7.76	0.12	0.72		2.1	65
		Flush					0.3	17
C10	Delta	1st Draw	7.45	0.09	0.75		0.3	216
		Flush					0.3	19
C11	Delta	1st Draw	7.71	0.14	0.57		2.7	274
		Flush					0.3	49
B3	Delta	1st Draw	7.68	0.11	0.69		5.4	239
		Flush					4.1	31

Figure A.2: Residential monitoring data – October 2011

			Oct-11					
Building	Faucet manufacturer		pH	Turbidity (NTU)	Cl_2 (mg/L)	Temperature ('C)	Lead (µg/L)	Copper (µg/L)
C3	Valley	1st Draw		0.11	0.17		0.065	68.61
		Flush		0.25	0.73		-0.023	11.73
C4	Waltec	1st Draw	7.7	0.28	0.07	21	5.303	213.1
		Flush	7.99	0.19	0.74	18.9	4.104	34.65
B1	No Name	1st Draw		0.33	0.06		12.21	79.67
		Flush		0.12	0.75		7.702	8.503
D1	Aristaline	1st Draw	7.7	0.17	0.1	21.8	0.39	66
		Flush	7.67	0.09	0.76	18.9	0.027	11.3
A1	Moen	1st Draw	7.64	0.18	0.2	22	1.23	66.92
		Flush	7.67	0.32	0.75	18.9	0.7	9.468
D3	Moen	1st Draw	7.6	0.12	0.28	18.6	1.502	103.2
		Flush	7.57	0.19	0.71	17.7	2.265	12.47
B2	Moen	1st Draw	7.51	0.35	0.67	17.5	3.718	38.25
		Flush					2.387	5.589
A2	Aristaline sink	1st Draw	7.52	0.1	0.47	21.8	0.19	97.54
		Flush	7.57	0.11	0.71	18.7	-0.022	8.821
D2	Steel Queen sink	1st Draw	7.53	0.48	0.02	22.7	2.861	174.4
		Flush	7.58	0.09	0.69	18.8	1.958	19.76
C6	Waltec	1st Draw	7.53	0.12	0.1	21.3	2.28	122.7
		Flush	7.61	0.17	0.63	18.8	0.208	24.06
A5	Waltec	1st Draw						
		Flush						
A6	Waltec	1st Draw		0.1	0.05		1.762	62.12
		Flush		0.11	0.76		0.937	10.25
C7	MKE Sink (unnamed)	1st Draw	7.52	0.3	0.12	18.1	0.378	134.7
		Flush	7.65	0.14	0.76	17.5	0.051	26.77
A3	Moen (clogged aerator)	1st Draw	7.66	0.2	0.55	18.3	16.15	71.38
		Flush	7.65	0.12	0.76	17.9	4.446	11.22
A4	Unnamed	1st Draw	7.65	0.14	0.07	17.8	2.379	173.9
		Flush	7.69	0.1	0.75	17.3	0.109	23.84
C5	Unnamed	1st Draw	7.68	0.26	0.1	18.8	2.869	183.8
		Flush	7.68	0.16	0.75	17.8	0.353	25.96
D5	2nd floor kitchenette	1st Draw		0.31	0.39		0.806	89.77
		Flush		0.11	0.73		0.089	14.67
D6	main floor kitchen, white	1st Draw		0.1	0.73		0.086	10.74
		Flush		0.09	0.76		0.015	11.11
C1	Waltec	1st Draw	7.57	0.32	0.07	19.2	1.674	314.3
		Flush	7.62	0.12	0.6	17.1	0.173	51.5
C2	Crane	1st Draw	7.54	0.27	0.36	19.8	1.394	92.43
		Flush	7.59	0.11	0.6	17	0.199	20.74
C8	Moen	1st Draw	7.66	0.32	0.07	22	11.38	230
		Flush	7.68	0.13	0.44	17.5	0.695	19.73
C15	Waltec 10	1st Draw		0.18	0.06		0.055	373.1
		Flush		0.12	0.57		0.038	35.15
C16	Waltec	1st Draw		0.11	0.03		3.865	127.5
		Flush		0.27	0.11		0.386	17.55
C17	Waltec	1st Draw	7.63	0.3	0.14	20.3	1.269	113.2
		Flush	7.61	0.17	0.59	16.2	0.071	19.87
C12	Emco	1st Draw	7.61	0.15	0.4	19.9	0.204	17.24
		Flush	7.63	0.24	0.51	18	0.015	4.712
C13	Waltec	1st Draw	-	0.26	0.19	-	2.275	56.87
		Flush	-	0.21	0.57	-	1.169	10.62
C14		1st Draw	-	-	-	-	-	-
		Flush	-	-	-	-	-	-
C18	Waltec	1st Draw	7.6	0.15	0.05	20.2	1.475	106.8
		Flush	7.69	0.1	0.62	18.1	0.095	15.09
D4	Waltec	1st Draw	7.6	0.25	0.11	19.5	1.254	76.06
		Flush	7.59	0.13	0.33	18.1	0.342	21.67
D7		1st Draw	-	0.27	0.04	-	0.561	141.3
		Flush	-	0.57	0.51	-	0.141	35.83
C9	Waltec (old one)	1st Draw	7.55	0.31	0.18	21	1.168	61.89
		Flush	7.59	0.13	0.7	17	0.155	15.99
C10	Delta	1st Draw	7.62	0.12	0.08	18.3	0.04	180.1
		Flush	7.62	0.11	0.68	16.8	-0.025	17.35
C11	Delta	1st Draw	7.52	0.16	0.08	20.3	1.569	228.6
		Flush	7.61	0.15	0.54	16.9	0.189	41.56
B3	Delta	1st Draw	7.67	0.12	0.03	20.7	2.412	209.9
		Flush	7.6	0.22	0.71	17.1	1.965	23.75

Table A.3: Residential monitoring data – February 2012

			Feb-12					
Building	Faucet manufacturer		pH	Turbidity (NTU)	Cl_2 (mg/L)	Temperature ('C)	Lead (μg/L)	Copper (μg/L)
C3	Valley	1st Draw		0.44	0.09		0.035	110.9
		Flush		0.67	0.28		-0.056	11.82
C4	Waltec	1st Draw		0.56	0.07		9.023	304
		Flush		0.38	0.55		2.339	26.4
B1	No Name	1st Draw		0.32	0.08		27.95	149.4
		Flush		0.55	0.32		11.91	12.02
D1	Aristaline	1st Draw		0.56	0.45		0.072	24.48
		Flush		0.44	0.47		-0.026	11.26
A1	Moen	1st Draw		0.56	0.07		2.314	86.17
		Flush		0.63	0.51		0.413	7.238
D3	Moen	1st Draw		0.4	0.09		2.508	131
		Flush		0.54	0.48		1.018	8.679
B2	Moen	1st Draw		0.29	0.25		5.685	75.46
		Flush		0.66	0.46		1.165	3.514
A2	Aristaline sink	1st Draw		0.32	0.31		-0.056	6.018
		Flush		0.38	0.48		-0.064	4.559
D2	Steel Queen sink	1st Draw		0.26	0.1		5.788	181.8
		Flush		0.65	0.54		0.909	13.63
C6	Waltec	1st Draw		0.65	0.02		5.262	172.2
		Flush		0.39	0.44		0.043	15.86
A5	Waltec	1st Draw						
		Flush						
A6	Waltec	1st Draw		0.24	0.07		4.367	84.6
		Flush		0.73	0.47		0.404	6.589
C7	MKE Sink (unnamed)	1st Draw	7.55	0.32	0.11	18.5	0.553	139.9
		Flush	7.72	0.36	0.46	6.6	-0.013	13.7
A3	Moen (clogged aerator)	1st Draw	7.4	0.49	0.12	18.4	28.55	275.4
		Flush	7.68	0.43	0.38	8.8	4.784	40.14
A4	Unnamed	1st Draw	7.57	0.3	0.08	15.7	8.928	371.1
		Flush	7.9	0.75	0.49	5.9	0.009	19.55
C5	Unnamed	1st Draw	7.58	0.42	0.13	14	6.43	235.1
		Flush	7.76	0.4	0.45	5.7	0.117	17.91
D5	2nd floor kitchenette	1st Draw	7.48	0.81	0.09	16.6	1.445	201.4
		Flush	7.69	0.44	0.58	6	-0.011	12.69
D6	main floor kitchen, white	1st Draw	7.71	0.33	0.46	10	0.296	12.87
		Flush	7.72	0.27	0.46	7.6	-0.039	8.985
C1	Waltec	1st Draw	7.79	0.43	0.06	17.4	4.517	455.6
		Flush	7.85	0.67	0.45	9.5	0.173	54.33
C2	Crane	1st Draw	7.63	0.23	0.2	17	2.831	127.3
		Flush		0.57	0.49	4.8	0.178	18.1
C8	Moen	1st Draw	7.71	0.58	0.07	15.9	24.11	498.3
		Flush	7.87	0.94	0.23	7.6	0.689	20.02
C15	Waltec 10	1st Draw	7.77	0.43	0.36	15.2	41.1	293.4
		Flush	7.86	0.24	0.39	7.5	0.52	24.23
C16	Waltec	1st Draw		0.45	0.1		8.787	213.4
		Flush		0.53	0.38		0.191	16.55
C17	Waltec	1st Draw	7.67	0.59	0.05	17.7	3.272	202.9
		Flush	7.75	0.26	0.35	8	0.091	18.68
C12	Emco	1st Draw	7.53	0.36	0.26	11.7	0.745	27.98
		Flush	7.66	0.32	0.29	5.2	0.031	4.544
C13	Waltec	1st Draw	7.54	0.54	0.12	21.6	5.626	111.1
		Flush	7.65	0.45	0.4	7.5	0.802	9.515
C14		1st Draw						
		Flush						
C18	Waltec	1st Draw	7.52	0.48	0.03	19.1	1.436	180.4
		Flush	7.67	0.44	0.33	9.7	0.055	14.21
D4	Waltec	1st Draw	7.61	0.27	0.1	19.2	1.888	128
		Flush	7.66	0.87	0.21	9.3	0.21	26.26
D7		1st Draw		0.27	0.04		1.608	258.9
		Flush		0.77	0.04		0.142	47.78
C9	Waltec (old one)	1st Draw	7.57	0.66	0.12	16.8	2.418	70.51
		Flush	7.72	0.77	0.43	6.3	0.105	8.736
C10	Delta	1st Draw	7.65	0.45	0.08	20.7	0.166	276.1
		Flush	7.77	0.52	0.44	6.9	0.061	13.87
C11	Delta	1st Draw	7.63	0.68	0.06	15.9	3.844	346.3
		Flush	7.79	0.56	0.43	6.3	0.151	33.45
B3	Delta	1st Draw	7.67	0.6	0.12	16.8	4.739	301.4
		Flush	7.81	0.89	0.46	6.9	1.034	16.93

Table A.4: Non-residential monitoring data – February 2011

			Feb-11					
Fountain/ Faucet	Location	Faucet manufacturer	pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp ('C)	Lead µg/L	Copper µg/L
Faucet	1st floor kitchenette	Meuller	7.23	0.31	0.27	25.9	14.6	410
Faucet	1st floor kitchenette (Newcombe)	Waltec						
Faucet	basement, kitchenette	Waltec						
Faucet	Main floor women's room	Waltec	7.46	0.3	0.14	22.8	5.1	379
Fountain	main floor, oceanography	Sunroc		0.4	0		1.5	566
Fountain	4th floor biology wing	Sunroc		0.31	0		2	371
Faucet	basement, women's room	Waltec	7.33	0.24	0.44	20.1	2.1	147
Fountain	1st floor by room 141	Crane	7.68	0.31	0.08	6.5	<0.5	275
Fountain	0 floor room 29	Crane	7.57	0.2	0.53	14.8	12.8	392
Fountain	0 floor room 1	Crane	7.42	0.27	0.12	21.4	4	519
Fountain	2nd floor room 210	Crane	7.28	0.29	0.12	28.4	1	220
Fountain	2nd floor room 228	Crane	7.27	0.24	0.15	22.3	6.9	577
Fountain	3rd floor room 343	Crane	7.19	0.39	0.15	18.4	13.1	1340
Fountain	3rd floor 337	Crane	7.17	0.31	0.12	26.8	4.6	651
Faucet	3rd floor board room	Delta	7.18	0.24	0.18	20.6	1.8	399
Fountain	1st floor fountain	Elkay	7.71	0.19	0.03	14.7	7.4	550
Fountain	3rd floor fountain	Elkay	7.64	0.25	0.11	11.7	10.3	274
Fountain	1st floor	American Standard	7.46	0.41	0.63	7	<0.5	141
Fountain	2nd floor	American Standard	7.42	0.2	0.01	18.1	2.4	383
Faucet	5th floor kitchen	Symmons	7.7	0.25	0.05	16	4.2	262
Fountain	3rd floor	Halsey Taylor	7.72	0.21	0.01	7.4	67.1	377
Fountain	5th floor	Oasis	7.74	0.3	0.05	4.8	1.6	147
Fountain	1st floor	Elkay EZH2O	7.68	0.24	0.01	8.9	<0.5	40
Fountain	2nd floor	Elkay	8.55	0.37	0.23	4.5	<0.5	83
Fountain	3rd floor	Elkay	8.42	0.26	0.06	5.7	<0.5	179
Fountain	1st floor by atrium stairs	Haws	7.38	0.3	0.01	7.8	<0.5	293
Fountain	1st floor in study lounge	Elkay EZH2O	7.41	0.34	0.01	7.6	<0.5	1160
Fountain	3rd floor	Haws	7.32	0.26	0.05	8	<0.5	457
Fountain	1st floor	Haws	7.43	0.94	0.04	2.4	0.5	894
Fountain	3rd floor	Haws	7.49	1.09	0.03	17.5	0.8	735
Fountain	1st Floor fountain		7.6	0.22	0.22	20.2	0.7	281
Fountain	4th floor fountain	Haws		0.31	0.04	18.8	0.8	285
Faucet	5th floor men's room	American Standard	7.23	0.55	0.01	21.1	1.8	242
Fountain	3rd floor	Halsey Taylor	7.25	0.72	0.06	12.2	**22.9**	645
Fountain	1st floor	Halsey Taylor	7.48	0.74	0.03	12.2	17.1	254
Fountain	2nd floor in law library	Haws	7.31	0.64	0.02	11.8	2.9	266
Fountain	1st floor by room 147	Haws	7.47	0.27	0.11	11	<0.5	295
Fountain	2nd floor by room 270	Haws	7.45	0.29	0.06	9.1	<0.5	266
Fountain	4th floor by room 422	Haws	7.42	0.3	0.05	8.9	0.5	437
Fountain	1st floor fountain		8.11	0.22	0.03	7.1	<0.5	268
Faucet	5th floor SRES Kitchenette		7.57	0.36	0.22	14.6	0.6	206
Faucet	3rd floor men's washroom		7.59	0.28	0.2	16.1	<0.5	209
Fountain	4th floor	Haws	7.46	0.93	0.04	2	<0.5	483
Fountain	2nd floorfountain	Sunroc						
Fountain	1st floor	Sunroc	7.42	0.33	0.01	17.5	2.3	902
Fountain	1st floor	Elkay EZH2O	7.62	0.18	0.05	14.3	<0.5	350
Faucet	2nd floor men's washroom left sink	Waltec	7.67	0.33	0.06	19.7	3.6	185
Faucet	4th floor men's room	American Standard		0.51	0.4		3.7	236
Fountain	Fountain by changerooms							
Faucet	Women's room	Waltec	7.47	1.62	0.04	11	14.8	226
Faucet	men's room (2nd from right)	Teck		0.51	0.4		6.8	312
Faucet	men's locker room (2nd from left)	Emco						
Faucet	Women's locker room	Emco fountain	7.51	0.63	0.02	11.9	0.6	136
Fountain	lobby	Super old fountain		0.18	0.13		<0.5	232
Faucet	1st floor, Blounge	Waltec	7.3	0.76	0.45	13.2	0.8	42
Faucet	2nd floor, bathroom (310, right sink)	Waltec		0.29	0.02		7.4	173

			Feb-11					
Fountain/ Faucet	Location	Faucet manufacturer	pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp ('C)	Lead µg/L	Copper µg/L
Fountain	cardio room	Oasis	7.47	0.26	0.01	5.8	<0.5	416
Fountain	hallway, near coaches office	Oasis	7.46	0.38	0.05	6.9	<0.5	315
Faucet	Fountain house, 1st floor washroom	Delta	7.38	0.19	0.02	23.7	<0.5	56
Faucet	Fountain house, 2nd floor kitchenette	Teck	7.36	0.18	0.49	10.8	1.5	27
Faucet	Bronson house, 2nd floor bathroom	Waltec	7.35	0.18	0	18.9	3.4	240
Faucet	Cameron house, 2nd floor bathroom	Waltec	7.25	1.36	0.44	16.1	<0.5	96
Faucet	Howe Hall dining room	Hussman food service	6.96	0.18	0.2	15	1.9	211
Faucet	Henderson house, 2nd floor bathroom	Waltec	7.3	1.1	0.17	19.6	<0.5	40
Faucet	1st floor bathroom	Waltec	7.37	0.57	0.54	18.3	0.5	94
Faucet	Basement Laundry Room		7.44	0.24	0.34	18.1	7.7	87
Faucet	1st floor kitchenette	Teck	7.69	0.66	0.38	6	<0.5	11
Faucet	1st floor coed bathroom	Delta	7.68	0.56	0.34	21.3	<0.5	17
Faucet	Bathroom in basement	Waltec	7.5	0.27	0.37	9.6	3.9	189
Fountain	3rd floor	Halsley W. Taylor Co.		0.14	0.05		2	162
Fountain	6th floor	Halsley W. Taylor Co.		0.2	0.02		8.7	520
Fountain	7th floor	Halsley W. Taylor Co.		0.21	0.07		8.1	796
Fountain	9th floor	Halsley W. Taylor Co.		0.21	0.05		12.6	550
Fountain	basement level	American Standard		0.2	0.07		16.6	278
Fountain	1st floor	American Standard		0.27	0.02		12.1	396
Fountain	3rd floor							
Fountain	3rd floor	Aquarius		0.56	0.05		1.5	685
Faucet	basement men's room	Waltec		0.2	0.34		3.6	121
Fountain	1st floor, dental clinic	Haws		0.13	0.05		1.8	433
Fountain	1st floor, clinic lab	Haws		0.97	0.05		4.6	914
Fountain	basement, below dental clinic fountain	Haws		0.51	0.02		2.3	696
Faucet	3rd floor kitchen sink	Teck	7.58	0.69	0.05	19.7	0.5	492
Faucet	3rd floor women's room	Teck	7.52	1.09	0.01	18.2	0.6	239
Fountain	1st floor fountain	Halsey Taylor						
Fountain	fountain near D002	Crane						
Fountain	fountain near D115B	Crane						
Fountain	fountain near D215	Crane	7.99	0.38	0.47	9.4	1.7	75
Fountain	fountain near D314	Crane	7.73	0.69	0.19	19.8	1.5	218
Fountain	Fountain on 4th floor	Halsey Taylor						
Fountain	fountain near D501	Halsey Taylor	7.69	0.36	0.06	19.6	7.7	481
Faucet	2nd floor women's room	Waltec	7.58	0.39	0.03	14.6	6.5	496
Fountain	Fountain near room 109							
Fountain	fountain near rm 051	Crane	7.78	0.28	0.15	17.9	35.2	1230
Fountain	fountain near rm 150	Crane	7.67	0.27	0.64	17.4	1.5	146
Fountain	fountain near 250	Crane	7.89	0.35	0.14	17.1	7.4	463
Faucet	Custodial Kitchen	Waltec						
Fountain	fountain near B316	American Standard	7.49	0.31	0.12	18.2	2.3	237
Fountain	fountain near B231	American Standard	7.41	0.35	0.09	19.2	2.9	390
Faucet	men's bathroom near café (left sink)	Symmons	8.2	0.71	0.37	10.7	0.5	140
Fountain	fountain near G207	Elkay	7.41	0.38	0.16	15.4	1	351
Faucet	2nd floor men's room	Waltec	7.38	0.32	0.59	18.7	15.4	181
Fountain	Fountain near F202	Temprite	7.48	0.28	0.1	11.2	1.9	514
Faucet	2nd floor men's room	Waltec	7.41	0.44	0.2	9.8	3.7	133
Fountain	fountain at entrance to Q building	Oasis	7.03	0.38	0.04	9.7	8.7	797
Faucet	2nd Floor Kitchenette	Teck						
Fountain	fountain on 2nd floor	Halsey Taylor	7.57	0.28	0.14	10.5	<0.5	319
Fountain	fountain, main floor	Oasis	7.7	0.33	0.09	7.6	<0.5	91
Fountain	downstairs fountain	Elkay	7.62	0.33	0.01	8.4	1.7	217
Fountain	fountain near P105	Elkay	7.25	0.59	0.1	16.1	4.1	822
Fountain	fountain near P202	Oasis	7.42	0.67	0.05	10.9	1.7	359
Faucet	women's washroom basement	Waltec	7.73	0.38	0.45	10.8	28.5	372
Faucet	kitchenette main floor	Waltec	7.67	0.53	0.04	18.5	2.5	238
Faucet	Women's Washroom main floor		7.44	0.22	0.01	19	2.7	167
Faucet	1st floor coed washroom	Moen	7.63	0.18	0.35	17.8	20.8	303
Faucet	2nd floor women's room	Waltec	7.57	2.75	0.29	18.8	9.8	169
Fountain	Gym fountain							

Table A.5: Non-residential monitoring data – October 2011

			Oct-11					
Fountain/ Faucet	Location	Faucet manufacturer	pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp. ('C)	Lead µg/L	Copper µg/L
Faucet	1st floor kitchenette	Meuller	7.43	0.33	0.06	23.7	8.376	409.5
Faucet	1st floor kitchenette (Newcombe)	Waltec	7.56	0.22	0.52	23.4	20.62	475.2
Faucet	basement, kitchenette	Waltec	7.61	0.65	0.65	20.2	7.388	386.9
Faucet	Main floor women's room	Waltec		0.26	0.2		2.355	154.3
Fountain	main floor, oceanography	Sunroc		0.5	0.09		0.299	356.2
Fountain	4th floor biology wing	Sunroc	7.59	0.41	0.02	13.1	0.992	232.3
Faucet	basement, women's room	Waltec	7.63	0.15	0.45	21.7	1.233	65.26
Fountain	1st floor by room 141	Crane	7.78	0.16	0.11	6.2	0.068	176.5
Fountain	0 floor room 29	Crane	7.59	0.24	0.62	22.1	2.397	272.2
Fountain	0 floor room 1	Crane	7.43	0.34	0.37	26.3	3.914	494.7
Fountain	2nd floor room 210	Crane		0.36	0.49		0.7	79.49
Fountain	2nd floor room 228	Crane	7.4	0.3	0.07	24.9	6.445	501
Fountain	3rd floor room 343	Crane		0.2	0.02		12.32	1107
Fountain	3rd floor 337	Crane	7.34	0.27	0.05	32.8	1.821	221.7
Faucet	3rd floor board room	Delta	7.57	0.42	0.08	23.4	0.94	243.5
Fountain	1st floor fountain	Elkay	7.64	0.71	0.02	12.4	2.383	336.1
Fountain	3rd floor fountain	Elkay	7.7	0.38	0.04	13.2	4.141	193.2
Fountain	1st floor	American Standard	7.67	0.24	0.62	18.1	0.04	105.5
Fountain	2nd floor	American Standard	7.43	0.22	0.01	22.8	0.573	207
Faucet	5th floor kitchen	Symmons	7.58	0.11	0.22	20.7	1.336	227.4
Fountain	3rd floor	Halsey Taylor	7.64	0.48	0.02	10.3	6.098	180.8
Fountain	5th floor	Oasis	7.71	0.33	0.2	8.2	0.482	109.6
Fountain	1st floor	Elkay EZH2O	7.61	0.21	0.02	11.9	0.003	110.8
Fountain	2nd floor	Elkay	7.75	0.32	0.5	6.3	0.051	55.69
Fountain	3rd floor	Elkay	7.66	0.47	0.36	11.9	0.006	116.2
Fountain	1st floor by atrium stairs	Haws	7.67	0.46	0.04	10	0.273	124.9
Fountain	1st floor in study lounge	Elkay EZH2O	8.34	0.47	0.02	12.9	0.052	54.44
Fountain	3rd floor	Haws		0.35	0.04		0.024	297.2
Fountain	1st floor	Haws	7.45	0.16	0.04	21.8	0.174	277.5
Fountain	3rd floor	Haws	7.52	0.7	0.05	10.4	0.201	602.4
Fountain	1st Floor fountain		8.47	0.44	0.08	8.6	0.136	392.2
Fountain	4th floor fountain	Haws	7.53	0.18	0.06	19.4	0.87	234.8
Faucet	5th floor men's room	American Standard	7.6	0.24	0.22	19.5	0.924	217
Fountain	3rd floor	Halsey Taylor	7.59	0.5	0.05	13.1	16.86	540.3
Fountain	1st floor	Halsey Taylor	7.66	0.76	0.11	10.8	9.756	207
Fountain	2nd floor in law library	Haws		0.33	0.26		1.653	158.6
Fountain	1st floor by room 147	Haws	7.63	0.3	0.05	11.8	0.019	256.5
Fountain	2nd floor by room 270	Haws	7.63	0.48	0.23	11.9	0.068	177.8
Fountain	4th floor by room 422	Haws	7.53	0.52	0.07	12.3	0.084	311.3
Fountain	1st floor fountain		7.62	0.9	0.23	12.4	0.01	184.4
Faucet	5th floor SRES Kitchenette			0.16	0.06		0.182	182.9
Faucet	3rd floor men's washroom			0.15	0.59		0.062	153.3
Fountain	4th floor	Haws	7.51	0.32	0.06	11.5	0.074	319.9
Fountain	2nd floorfountain	Sunroc	7.55	0.22	0.08	9.8	0.925	648.9
Fountain	1st floor	Sunroc		0.19	0.07		0.419	323
Fountain	1st floor	Elkay EZH2O	7.64	0.14	0.32	13.8	0.008	89.98
Faucet	2nd floor men's washroom left sink	Waltec	7.62	0.13	0.42	18.8	1.127	94.87
Faucet	4th floor men's room	American Standard		0.15	0.34		1.493	145.8
Fountain	Fountain by changerooms		7.68	0.13	0.43	12.7	0.037	45.41
Faucet	Women's room	Waltec						
Faucet	men's room (2nd from right)	Teck		0.53	0.42		27.48	222.8
Faucet	men's locker room (2nd from left)	Emco	7.5	0.47	0.29	24.7	1.372	113.7
Faucet	Women's locker room	Emco fountain						
Fountain	lobby	Super old fountain		0.54	0.04		0.114	227.1
Faucet	1st floor, Blounge	Waltec	7.66	0.12	0.76	19.1	7.05	39.04
Faucet	2nd floor, bathroom (310, right sink)	Waltec		0.54	0.63		3.381	59.85

			Oct-11					
Fountain/ Faucet	Location	Faucet manufacturer	pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp. ('C)	Lead µg/L	Copper µg/L
Fountain	cardio room	Oasis		0.6	0.17		0.015	258.4
Fountain	hallway, near coaches office	Oasis	7.71	0.55	0.13	8.5	0.024	229.9
Faucet	Fountain house, 1st floor washroom	Delta	7.44	0.23	0.69	21.7	0.019	24.08
Faucet	Fountain house, 2nd floor kitchenette	Teck	7.41	0.26	0.13	21.9	0.792	56.65
Faucet	Bronson house, 2nd floor bathroom	Waltec	7.46	0.17	0.54	22.4	1.904	72.61
Faucet	Cameron house, 2nd floor bathroom	Waltec	7.58	0.2	0.65	20.7	0.772	79.48
Faucet	Howe Hall dining room	Hussman food service						
Faucet	Henderson house, 2nd floor bathroom	Waltec		0.28	0.64		0.352	38.78
Faucet	1st floor bathroom	Waltec		0.26	0.43		0.328	111.2
Faucet	Basement Laundry Room							
Faucet	1st floor kitchenette	Teck	7.54	0.56	0.48	25.4	0.071	16.06
Faucet	1st floor coed bathroom	Delta	7.57	0.21	0.67	23.7	0.062	27.88
Faucet	Bathroom in basement	Waltec		0.18	0.64		1.297	52.7
Fountain	3rd floor	Halsley W. Taylor Co.		0.34	0.04		1.878	149.7
Fountain	6th floor	Halsley W. Taylor Co.	7.46	0.44	0.03	17.4	4.221	400.5
Fountain	7th floor	Halsley W. Taylor Co.	7.24	0.66	0.07	26.9	4.538	571.6
Fountain	9th floor	Halsley W. Taylor Co.		0.29	0.06		8.206	423.7
Fountain	basement level	American Standard	7.45	0.13	0.55	22.2	8.269	172.6
Fountain	1st floor	American Standard	7.46	0.13	0.03	22.1	6.439	315.6
Fountain	3rd floor		7.64	0.3	0.26	11.5	0.637	90.51
Fountain	3rd floor	Aquarius	7.54	0.69	0.04	10.1	0.584	458.4
Faucet	basement men's room	Waltec		0.15	0.58		1.47	59.66
Fountain	1st floor, dental clinic	Haws	7.43	0.12	0.04	22.6	0.859	223.6
Fountain	1st floor, clinic lab	Haws	7.49	0.53	0.02	13	2.267	569.4
Fountain	basement, below dental clinic fountain	Haws	7.48	0.24	0.04	14	1.008	399.6
Faucet	3rd floor kitchen sink	Teck	7.41	0.18	0.04	18.6	0.109	230.5
Faucet	3rd floor women's room	Teck						
Fountain	1st floor fountain	Halsey Taylor	7.55	0.62	0.04	10.6	1.09	152.2
Fountain	fountain near D002	Crane						
Fountain	fountain near D115B	Crane						
Fountain	fountain near D215	Crane	7.38	0.47	0.62	20.2	0.452	50.45
Fountain	fountain near D314	Crane						
Fountain	Fountain on 4th floor	Halsey Taylor	7.6	0.12	0.03	14	0.424	98.38
Fountain	fountain near D501	Halsey Taylor	7.56	0.28	0.07	10.6	2.463	274.5
Faucet	2nd floor women's room	Waltec						
Fountain	Fountain near room 109		7.64	0.04	0.35	10.6	1.583	280.7
Fountain	fountain near rm 051	Crane	7.41	0.47	0.04	18.7	48.86	1039
Fountain	fountain near rm 150	Crane	7.52	0.23	0.04	18.3	3.008	260.7
Fountain	fountain near 250	Crane	7.54	0.26	0.04	18.6	3.8	454.7
Faucet	Custodial Kitchen	Waltec	7.13	0.2	0.07	19.7	5.161	392.1
Fountain	fountain near B316	American Standard	7.47	0.25	0.28	21	1.764	156
Fountain	fountain near B231	American Standard	7.48	0.3	0.43	20.9	2.322	237.9
Faucet	men's bathroom near café (left sink)	Symmons		0.38	0.51		0.94	70.59
Fountain	fountain near G207	Elkay		0.57	0.04		0.099	160.1
Faucet	2nd floor men's room	Waltec		0.94	0.13		8.338	249.4
Fountain	Fountain near F202	Temprite		0.91	0.07		1.158	317.7
Faucet	2nd floor men's room	Waltec		0.36	0.27		3.824	129.5
Fountain	fountain at entrance to Q building	Oasis	7.44	0.81	0.01	12.5	11.71	1109
Faucet	2nd Floor Kitchenette	Teck	7.36	0.46	0.14	24.7	2.39	366
Fountain	fountain on 2nd floor	Halsey Taylor		0.55	0.35		0.028	160.5
Fountain	fountain, main floor	Oasis	7.56	0.28	0.45	11.5	0.018	43.49
Fountain	downstairs fountain	Elkay	7.42	0.15	0.17	13.2	0.602	121
Fountain	fountain near P105	Elkay	7.37	0.16	0.03	16.7	2.515	427.7
Fountain	fountain near P202	Oasis	7.38	0.77	0.01	12.1	1.063	244.6
Faucet	women's washroom basement	Waltec		0.49	0.09		18.84	235.7
Faucet	kitchenette main floor	Waltec		0.43	0.06		1.455	179.4
Faucet	Women's Washroom main floor							
Faucet	1st floor coed washroom	Moen		0.18	0.45		12.06	136.4
Faucet	2nd floor women's room	Waltec						
Fountain	Gym fountain							

Table A.6: Non-residential monitoring data – February 2012

			Feb-12					
Fountain/ Faucet	Location	Faucet manufacturer	pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp. ('C)	Lead µg/L	Copper µg/L
Faucet	1st floor kitchenette	Meuller	7.49	0.49	0.05	21.4	24.4	751.4
Faucet	1st floor kitchenette (Newcombe)	Waltec	7.55	0.46	0.07	21.5	68.93	904.5
Faucet	basement, kitchenette	Waltec						
Faucet	Main floor women's room	Waltec		0.65	0.15		2.27	141
Fountain	main floor, oceanography	Sunroc	7.51	0.31	0.04	10.6	1.125	641
Fountain	4th floor biology wing	Sunroc	7.45	0.89	0.03	12.2	1.812	461.8
Faucet	basement, women's room	Waltec		0.41	0.12		5.683	177.4
Fountain	1st floor by room 141	Crane	7.59	0.23	0.07	5.7	0.27	323.1
Fountain	0 floor room 29	Crane	7.82	0.64	0.2	12.3	9.955	542.8
Fountain	0 floor room 1	Crane		0.29	0.15		5.932	736.5
Fountain	2nd floor room 210	Crane	7.24	0.16	0.05	37	0.93	223.3
Fountain	2nd floor room 228	Crane		0.37	0.15		9.496	500.8
Fountain	3rd floor room 343	Crane	7.57	0.76	0.05	21.2	14.38	1315
Fountain	3rd floor 337	Crane	7.3	0.47	0.03	30.3	2.646	475.8
Faucet	3rd floor board room	Delta	7.44	0.4	0.13	21.4	1.735	489.3
Fountain	1st floor fountain	Elkay	7.59	0.57	0.08	12.8	7.718	695.9
Fountain	3rd floor fountain	Elkay	7.51	0.3	0.11	12.6	16.25	351.4
Fountain	1st floor	American Standard	7.77	0.47	0.38	8.7	0.09	194.9
Fountain	2nd floor	American Standard	7.42	0.21	0.07	20.9	1.873	343.3
Faucet	5th floor kitchen	Symmons	7.56	0.57	0.12	19.8	3.327	431.2
Fountain	3rd floor	Halsey Taylor	7.61	0.25	0.04	9.6	21.58	267.6
Fountain	5th floor	Oasis	7.45	0.28	0.08	9	1.427	185.4
Fountain	1st floor	Elkay EZH2O	7.61	0.93	0.09	11.6	0.066	146.3
Fountain	2nd floor	Elkay	7.63	0.36	0.05	5.7	0.408	100.5
Fountain	3rd floor	Elkay	7.62	0.39	0.07	11.4	0.212	230.5
Fountain	1st floor by atrium stairs	Haws	7.71	0.95	0.1	10.5	0.622	366.5
Fountain	1st floor in study lounge	Elkay EZH2O	7.67	0.23	0.17	11	0.084	724
Fountain	3rd floor	Haws		1.05	0.07		0.113	459.2
Fountain	1st floor	Haws	7.48	0.52	0.07	20.2	0.647	990.1
Fountain	3rd floor	Haws	7.54	0.76	0.05	10	0.794	1445
Fountain	1st Floor fountain			0.82	0.05		0.349	277.8
Fountain	4th floor fountain	Haws		0.23	0.1		1.043	271.7
Faucet	5th floor men's room	American Standard		0.32	0.09		4.906	600.7
Fountain	3rd floor	Halsey Taylor		0.83	0.05		54.99	855.8
Fountain	1st floor	Halsey Taylor		0.29	0.04		16.81	229.1
Fountain	2nd floor in law library	Haws		0.32	0.07		2.536	158.1
Fountain	1st floor by room 147	Haws		0.79	0.06		0.32	331.2
Fountain	2nd floor by room 270	Haws	7.62	0.68	0.08	10.4	0.252	278.3
Fountain	4th floor by room 422	Haws	7.35	0.32	0.08	10.5	0.499	362.5
Fountain	1st floor fountain			0.89	0.08		0.101	290
Faucet	5th floor SRES Kitchenette			0.43	0.05		0.405	185
Faucet	3rd floor men's washroom			0.7	0.29		0.141	235.8
Fountain	4th floor	Haws	7.63	0.59	0.1	11.7	0.302	757.4
Fountain	2nd floorfountain	Sunroc	7.48	0.69	0.03	14	2.497	739.2
Fountain	1st floor	Sunroc	7.79	0.46	0.09	10.4	1.747	472.7
Fountain	1st floor	Elkay EZH2O	7.53	0.43	0.04	13	0.078	358.2
Faucet	2nd floor men's washroom left sink	Waltec	7.56	0.26	0.15	20.2	4.367	284.3
Faucet	4th floor men's room	American Standard		0.28	0.16		4.272	325.9
Fountain	Fountain by changerooms		7.67	0.54	0.05	10.5	0.538	122.1
Faucet	Women's room	Waltec	-	-	-	-		
Faucet	men's room (2nd from right)	Teck						
Faucet	men's locker room (2nd from left)	Emco	7.56	0.36	0.16	20.3	5.768	327.1
Faucet	Women's locker room	Emco fountain	-	-	-	-		
Fountain	lobby	Super old fountain	7.47	0.19	0.13	25	0.224	308.6
Faucet	1st floor, Blounge	Waltec						
Faucet	2nd floor, bathroom (310, right sink)	Waltec						

			Feb-12					
Fountain/ Faucet	Location	Faucet manufacturer	pH	Turbidity (NTU)	Cl_2 (mg/L)	Temp. ('C)	Lead µg/L	Copper µg/L
Fountain	cardio room	Oasis		0.67	0.09		0.046	134.8
Fountain	hallway, near coaches office	Oasis	7.77	0.78	0.05	10.9	0.074	288.3
Faucet	Fountain house, 1st floor washroom	Delta	7.4	0.2	0.11	16.1	1.854	237.5
Faucet	Fountain house, 2nd floor kitchenette	Teck	7.53	0.21	0.11	20.1	0.34	32.04
Faucet	Bronson house, 2nd floor bathroom	Waltec	7.48	0.4	0.09	17.5	7.446	378.4
Faucet	Cameron house, 2nd floor bathroom	Waltec	7.59	0.42	0.21	18.9	1.795	119.7
Faucet	Howe Hall dining room	Hussman food service						
Faucet	Henderson house, 2nd floor bathroom	Waltec		0.23	0.28		0.726	77.16
Faucet	1st floor bathroom	Waltec	7.55	0.18	0.19	20.1	0.636	111.4
Faucet	Basement Laundry Room							
Faucet	1st floor kitchenette	Teck	7.55	0.51	0.22	20.7	0.173	13.28
Faucet	1st floor coed bathroom	Delta	7.46	0.47	0.06	24.4	0.248	23.34
Faucet	Bathroom in basement	Waltec		0.23	0.07		3.565	189.4
Fountain	3rd floor	Halsley W. Taylor Co.	7.56	0.26	0.08	22	2.216	170.4
Fountain	6th floor	Halsley W. Taylor Co.	7.66	0.6	0.06	15.1	8.302	532
Fountain	7th floor	Halsley W. Taylor Co.	7.35	0.26	0.06	27.5	7.053	798.8
Fountain	9th floor	Halsley W. Taylor Co.	7.36	0.24	0.07	24.7	14.58	605.8
Fountain	basement level	American Standard	7.65	0.57	0.11	20.3	14.65	242.9
Fountain	1st floor	American Standard	7.56	0.53	0.07	21.9	20.33	460
Fountain	3rd floor		7.7	0.28	0.04	11.8	1.619	211.2
Fountain	3rd floor	Aquarius	7.67	0.63	0.1	8.9	1.582	689.3
Faucet	basement men's room	Waltec		0.48	0.07		3.513	125.9
Fountain	1st floor, dental clinic	Haws	7.51	0.18	0.04	21.9	1.39	328.3
Fountain	1st floor, clinic lab	Haws						
Fountain	basement, below dental clinic fountain	Haws	7.64	0.45	0.1	15.9	3.398	526.7
Faucet	3rd floor kitchen sink	Teck	7.66	0.44	0.08	18.5	0.536	426.7
Faucet	3rd floor women's room	Teck						
Fountain	1st floor fountain	Halsey Taylor	7.69	0.43	0.08	10.9	3.371	235.7
Fountain	fountain near D002	Crane						
Fountain	fountain near D115B	Crane						
Fountain	fountain near D215	Crane	7.8	0.31	0.3	11.6	0.955	107.1
Fountain	fountain near D314	Crane						
Fountain	Fountain on 4th floor	Halsey Taylor	7.64	0.24	0.09	12.2	1.364	159.8
Fountain	fountain near D501	Halsey Taylor	7.56	0.67	0.08	12.2	8.152	477.2
Faucet	2nd floor women's room	Waltec						
Fountain	Fountain near room 109		7.42	0.2	0.06	12.4	0.184	239.5
Fountain	fountain near rm 051	Crane						
Fountain	fountain near rm 150	Crane	7.5	0.3	0.19	24.2	4.614	295.4
Fountain	fountain near 250	Crane	7.49	0.39	0.19	24.3	4.366	528.8
Faucet	Custodial Kitchen	Waltec						
Fountain	fountain near B316	American Standard	7.55	0.39	0.08	19.9	2.171	211.9
Fountain	fountain near B231	American Standard	7.45	0.26	0.11	22.5	3.152	357.2
Faucet	men's bathroom near café (left sink)	Symmons		0.29	0.23		1.515	98.75
Fountain	fountain near G207	Elkay	7.56	2.43	0.06	11.2	0.701	311.1
Faucet	2nd floor men's room	Waltec		0.3	0.3		6.614	216.9
Fountain	Fountain near F202	Temprite	7.44	0.31	0.06	22.7	2.744	558.9
Faucet	2nd floor men's room	Waltec	7.66	0.36	0.33	13.5	6.951	162.8
Fountain	fountain at entrance to Q building	Oasis		0.6	0.01		9.362	1154
Faucet	2nd Floor Kitchenette	Teck	7.45	0.32	0.13	22	6.22	311
Fountain	fountain on 2nd floor	Halsey Taylor	7.67	0.3	0.07	8.8	0.067	206.9
Fountain	fountain, main floor	Oasis	7.56	0.41	0.11	11.7	2.614	221.2
Fountain	downstairs fountain	Elkay	7.6	0.52	0.2	11.4	0.49	63.99
Fountain	fountain near P105	Elkay	7.46	0.3	0.08	17.3	5.675	714.2
Fountain	fountain near P202	Oasis	7.58	0.61	0.04	7.9	1.868	380.1
Faucet	women's washroom basement	Waltec						
Faucet	kitchenette main floor	Waltec	7.54	0.34	0.05		3.837	413.5
Faucet	Women's Washroom main floor							
Faucet	1st floor coed washroom	Moen		0.93	0.32	18.5	3.277	97.81
Faucet	2nd floor women's room	Waltec						
Fountain	Gym fountain		7.46	0.67	0.07	12.2	0.493	317.6

Appendix B – Drinking Fountain Investigation

Table B.1: Fountain investigation results – June 15, 2011

			June 15, 2011									% Particulate				
Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
Chemistry	3rd floor fountain	1 - 250 mL	7.20	0.17	0.49	13.3	17.92	188.5	181.1	1.628	4.831	82.96317	71.82493	31.91607	58.59951	89.691575
		1 -d					3.053	53.11	123.3	0.674	0.498					
		2 - 250 mL					15.48	213.4	121.1	1.133	4.432					
		3 - 250 mL					12.53	213.2	121.3	1.312	4.084	55.04389	24.06191	12.6958	70.12195	54.3095
		3 -d					5.633	161.9	105.9	0.392	1.866					
		4 - 250 mL					9.475	197.3	122.1	0.825	5.232					
		5 - 500 mL					9.045	175.4	126	0.958	5.235	74.92537	26.7959	14.92063	66.49269	52.531041
		5 -d					2.268	128.4	107.2	0.321	2.485					
		6 - 500 mL					8.633	151	128.6	1.51	6.023					
		7 - 1000 mL					5.486	122.8	129.5	0.82	4.672					
Chemistry	5th floor fountain	1 - 250 mL	7.15	0.63	0.38	12.1	0.763	95.09	156.6	9.192	3.662	67.75885	18.87685	39.29119	62.4456	95.931185
		1 -d					0.246	77.14	95.07	3.452	0.149					
		2 - 250 mL					0.586	98.32	101.8	8.264	0.888					
		3 - 250 mL					0.603	96.13	98.15	7.092	0.56	63.51575	28.59669	13.07183	61.87253	131.42857
		3 -d					0.22	68.64	85.32	2.704	-0.176					
		4 - 250 mL					0.521	88.99	96.83	6.637	0.001					
		5 - 500 mL					0.54	82.12	101.1	5.471	5.196	60	21.07891	10.34619	49.35112	90.204003
		5 -d					0.216	64.81	90.64	2.771	0.509					
		6 - 500 mL					0.542	78.6	102.7	6.195	0.442					
		7 - 1000 mL					0.478	72.78	108.1	4.828	0.493	53.9749	21.723	11.48936	44.73902	-202.2312
		7 -d					0.22	56.97	95.68	2.668	1.49					
Law	1st floor fountain	1 - 250 mL		0.32	0.32		19.19	226.6	249.5	0.232	26.3	36.21678	26.47838	17.43487	-40.9483	28.365019
		1 -d					12.24	166.6	206	0.327	18.84					
		2 - 250 mL					17.93	263.8	219.7	0.227	27.85					
		3 - 250 mL					12.98	288.2	193.8	0.158	22.17	43.84438	26.19709	17.80186	-16.4557	35.543527
		3 -d					7.289	212.7	159.3	0.184	14.29					
		4 - 250 mL					9.089	284.6	183.1	0.144	19.68					
		5 - 500 mL					6.079	254	170.2	0.172	22.26	43.4282	21.69291	14.86486	-4.06977	30.143756
		5 -d					3.439	198.9	144.9	0.179	15.55					
		6 - 500 mL					4.652	219.1	159.4	0.292	32.88					
		7 - 1000 mL					4.208	209.2	195.7	0.429	54.17	64.56749	51.29063	40.5723	29.37063	50.00923
		7 -d					1.491	101.9	116.3	0.303	27.08					
Law	2nd floor Library fountain	1 - 250 mL		0.22	0.39		3.298	159.5	262.6	0.182	25.04	60.18799	16.17555	53.84615	4.395604	22.563898
		1 -d					1.313	133.7	121.2	0.174	19.39					
		2 - 250 mL					3.85	168.4	175.4	0.122	27.27					
		3 - 250 mL					4.497	185.3	104.1	0.158	20.22	32.84412	24.01511	11.81556	0	19.58457
		3 -d					3.02	140.8	91.8	0.158	16.26					
		4 - 250 mL					4.062	173.2	106.1	0.121	20.93					
		5 - 500 mL					3.685	148.6	111.6	0.149	25.1	36.49932	21.19785	10.43907	-3.3557	13.665339
		5 -d					2.34	117.1	99.95	0.154	21.67					
		6 - 500 mL					2.955	123	117.3	0.361	29.97					
		7 - 1000 mL					2.309	97.72	123.8	0.201	27.81					
		7 -d														
Law	3rd floor fountain	1 - 250 mL		6.53	0.30		97.51	4683	462.6	1.504	428.4	92.60281	90.99295	31.02032	90.625	98.005135
		1 -d					7.213	421.8	319.1	0.141	8.546					
		2 - 250 mL					142.2	7261	329.5	2.256	699.7					
		3 - 250 mL					100.2	5275	275.6	2.163	499.1	95.52295	91.47867	36.39332	96.48636	99.29974
		3 -d					4.486	449.5	175.3	0.076	3.495					
		4 - 250 mL					76.87	4495	253	1.424	416.2					
		5 - 500 mL					56.63	3394	227.9	1.203	318.9	91.71464	88.73895	30.01316	92.1862	96.142992
		5 -d					4.692	382.2	159.5	0.094	12.3					
		6 - 500 mL					74.08	6568	283.8	1.759	563.1					
		7 - 1000 mL					119.7	10120	303	1.815	855.4	97.82038	96.98024	53.59736	93.99449	98.585457
		7 -d					2.609	305.6	140.6	0.109	12.1					

Table B.2: Fountain investigation results – June 30, 2011

													% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	C1	2nd	1 - 250 mL	7.46	0.33	0.13	20.4	5.226	533.3	654.2	-0.067	15.23	62.95446	40.09001	44.90981	-58.209	39.59947472
			1 -d					1.936	319.5	360.4	-0.106	9.199					
			2 - 250 mL					1.224	192.8	182.6	-0.157	16.06					
			3 - 250 mL					1.355	196.1	143.3	-0.169	11.3	61.91882	28.76084	20.9351	7.692308	46.80530973
			3 -d					0.516	139.7	113.3	-0.156	6.011					
			4 - 250 mL					0.914	160.4	117	-0.178	6.221					
			5 - 1000 mL					0.675	128.4	94.93	-0.181	7.148	46.96296	22.11838	7.742547	6.629834	21.01287073
			5 -d					0.358	100	87.58	-0.169	5.646					
			6 - 1000 mL					0.581	69.66	88.07	-0.183	9.223	51.63511	22.15045	8.867946	7.103825	29.69749539
			6 -d					0.281	54.23	80.26	-0.17	6.484					
B	C1	1st	1 - 250 mL	7.67	0.17	0.31	18.7	2.182	185.8	125.3	-0.077	8.01	51.69569	27.87944	13.80686	-61.039	22.87141074
			1 -d					1.054	134	108	-0.124	6.178					
			2 - 250 mL					1.217	80.45	88.14	-0.17	7.058					
			3 - 250 mL					0.473	54.92	76.81	-0.175	7.849	55.60254	24.563	11.36571	6.285714	35.1764556
			3 -d					0.21	41.43	68.08	-0.164	5.088					
			4 - 250 mL					0.463	54.55	78.76	-0.183	8.024					
			5 - 1000 mL					0.359	43.36	71.45	-0.183	8.661	47.07521	19.9262	9.769069	8.196721	35.90809375
			5 -d					0.19	34.72	64.47	-0.168	5.551					
			6 - 1000 mL					0.34	42.87	72.35	-0.187	7.926	49.41176	28.22487	11.80373	8.02139	31.18849357
			6 -d					0.172	30.77	63.81	-0.172	5.454					
C	C1	0 floor	1 - 250 mL	7.75	0.2	0.33	18.1	30.69	714.4	407.3	-0.069	15.16	51.48257	21.72452	13.28259	-85.5072	57.48021108
			1 -d					14.89	559.2	353.2	-0.128	6.446					
			2 - 250 mL					5.802	501.7	151.8	-0.152	10.35					
			3 - 250 mL					4.273	168.9	157.8	-0.155	15.13	61.29183	29.24808	35.80482	-2.58065	64.87772637
			3 -d					1.654	119.5	101.3	-0.159	5.314					
			4 - 250 mL					3.574	106.6	138.4	-0.171	9.783					
			5 - 1000 mL					2.23	94.97	122.4	-0.174	11.06	49.59641	25.52385	32.67157	5.747126	55.12658228
			5 -d					1.124	70.73	82.41	-0.164	4.963					
			6 - 1000 mL					2.371	86.48	136.1	-0.181	13.17	54.82919	30.35384	42.26304	5.524862	72.00455581
			6 -d					1.071	60.23	78.58	-0.171	3.687					
D	Dunn	1st	1 - 250 mL	7.64	0.19	0.58	17	0.105	112.4	91.82	-0.078	-1.961	-39.0476	28.55872	3.016772	-43.5897	78.32738399
			1 -d					0.146	80.3	89.05	-0.112	-0.425					
			2 - 250 mL					-0.009	16.24	76.73	-0.172	1.688					
			3 - 250 mL					0.081	10.74	71.56	-0.174	1.894	-65.4321	20.24209	4.192286	10.34483	95.77613516
			3 -d					0.134	8.566	68.56	-0.156	0.08					
			4 - 250 mL					0.011	12.18	71.7	-0.184	0.819					
			5 - 1000 mL					0.005	8.711	70.46	-0.188	1.425	-360	15.49765	6.741414	8.510638	109.2631579
			5 -d					0.023	7.361	65.71	-0.172	-0.132					
			6 - 1000 mL					0.017	8.968	69.41	-0.189	0.899	-82.3529	13.35861	2.2187	10.58201	189.9888765
			6 -d					0.031	7.77	67.87	-0.169	-0.809					
E	Dunn	2nd	1 - 250 mL	7.44	0.16	0.07	21.4	0.974	254.3	178.1	-0.086	-0.001	58.7269	37.35745	22.40314	-47.6744	-455300
			1 -d					0.402	159.3	138.2	-0.127	-4.554					
			2 - 250 mL					0.75	144	103.8	-0.168	-4.566					
			3 - 250 mL					0.643	132.4	351.5	-0.171	18.68	83.51477	40.95166	73.85206	7.017544	118.3618844
			3 -d					0.106	78.18	91.91	-0.159	-3.43					
			4 - 250 mL					0.425	134.9	96.14	-0.179	-4.925					
			5 - 1000 mL					0.374	122.4	161.9	-0.182	2.337	54.27807	25.19608	48.71526	4.945055	265.3829696
			5 -d					0.171	91.56	83.03	-0.173	-3.865					
			6 - 1000 mL					0.302	116.1	87.15	-0.187	-4.691	18.21192	25.89147	9.558233	8.55615	-3.943722021
			6 -d					0.247	86.04	78.82	-0.171	-4.876					
F	Chase	1st	1 - 250 mL	7.68	0.26	0.29	14	2.487	376.7	178.4	-0.072	16.27	39.16365	24.71463	29.70852	-84.7222	89.7664413
			1 -d					1.513	283.6	125.4	-0.133	1.665					
			2 - 250 mL					3.283	367.9	372.3	-0.167	25.81					
			3 - 250 mL					5.024	342.7	234.4	-0.165	18.68	49.28344	27.51678	43.17406	-2.42424	97.19486081
			3 -d					2.548	248.4	133.2	-0.169	0.524					
			4 - 250 mL					5.064	307.9	249.5	-0.18	21.86					
			5 - 1000 mL					4.314	235.2	228	-0.177	22.07	43.09226	18.53741	53.24561	0.564972	96.39329406
			5 -d					2.455	191.6	106.6	-0.176	0.796					
			6 - 1000 mL					3.023	134.8	215.7	-0.175	10.9	54.94542	26.26113	60.60269	-2.28571	65
			6 -d					1.362	99.4	84.98	-0.179	3.815					
G	Chase	3rd	1 - 250 mL	7.64	0.14	0.05	14.7	4.838	190.2	993.9	-0.08	6.117	46.36213	33.54364	20.07244	-58.75	120.6310283
			1 -d					2.595	126.4	794.4	-0.127	-1.262					
			2 - 250 mL					5.283	213.5	996.9	-0.161	8.125					
			3 - 250 mL					7.176	218.2	1292	-0.168	61.25	58.20792	32.72227	48.05728	0.595238	101.557551
			3 -d					2.999	146.8	671.1	-0.167	-0.954					
			4 - 250 mL					7.857	214.3	683.6	-0.179	4.782					
			5 - 1000 mL					6.949	201	573.5	-0.157	5.965	55.28853	34.12935	15.81517	-10.1911	127.2087175
			5 -d					3.107	132.4	482.8	-0.173	-1.623					
			6 - 1000 mL					8.522	222.4	466.5	-0.075	5.594	74.20793	56.47482	9.817792	-133.333	102.538434
			6 -d					2.198	96.8	420.7	-0.175	-0.142					

Table B.3: Fountain investigation results – July 7, 2011

													% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	Weldon Law	3rd floor men's room	1 - 250 mL	7.8	0.22	0.34	20	22.73	337.6	519.9	0.236	11.27	58.67576	34.21209	14.59896	-8.47458	18.15439219
			1 -d					9.393	222.1	444	0.256	9.224					
			2 - 250 mL					9.173	265.5	192.6	0.09	15.92					
			3 - 250 mL					3.28	89.79	136.1	-0.117	38.65	41.0061	42.06482	11.68259	123.9316	24.34670116
			3 -d					1.935	52.02	120.2	0.028	29.24					
			4 - 250 mL					3.164	75.53	137.2	-0.22	37.4					
			5 - 1000 m					2.67	70.82	104.2	-0.148	30.05	-19.2509	40.35583	12.70633	117.5676	30.31613977
			5 -d					3.184	42.24	90.96	0.026	20.94					
			6 - 1000 m					1.867	57.21	97.03	-0.184	20.93	20.51419	24.13914	2.246728	83.15217	26.61251792
			6 -d					1.484	43.4	94.85	-0.031	15.36					
B	LSC	main floor oceanography	1 - 250 mL	7.52	0.19	0.14	15.6	0.492	362.9	125.7	-0.025	13.62	-42.4797	27.22513	6.046142	140	17.18061674
			1 -d					0.701	264.1	118.1	0.01	11.28					
			2 - 250 mL					0.432	274.9	303.8	-0.217	29.17					
			3 - 250 mL					0.671	227.5	138.3	-0.191	11.71	-5.2161	36.30769	5.639913	69.63351	26.1058924
			3 -d					0.706	144.9	130.5	-0.058	8.653					
			4 - 250 mL					0.734	196.7	102	-0.249	10.24					
			5 - 1000 m					0.368	134.7	84.61	-0.234	17.84	-47.8261	43.18486	9.230587	48.71795	7.679372197
			5 -d					0.544	76.53	76.8	-0.12	16.47					
			6 - 1000 m					0.351	74.11	200.6	-0.311	31.92	-50.1425	31.03495	57.89631	51.1254	34.3358396
			6 -d					0.527	51.11	84.46	-0.152	20.96					
C	LSC	4th floor Biology	1 - 250 mL	7.16	3.21	0.44	14.5	0.695	258.2	90.17	-0.069	21.91	3.309353	42.83501	9.981147	69.56522	22.77498859
			1 -d					0.672	147.6	81.17	-0.021	16.92					
			2 - 250 mL					0.697	214.5	126.8	-0.266	22.89					
			3 - 250 mL					2.48	167.1	104.8	-0.255	21.15	40.96774	42.0766	25.82061	35.68627	20.52009456
			3 -d					1.464	96.79	77.74	-0.164	16.81					
			4 - 250 mL					0.962	91.39	137	-0.305	43.31					
			5 - 1000 m					0.547	54.19	70.3	-0.326	50.38	-11.7002	32.93966	13.98293	43.86503	25.62524811
			5 -d					0.611	36.34	60.47	-0.183	37.47					
			6 - 1000 m					0.532	50.56	116	-0.356	51.43	-95.3008	22.23101	10.34483	50	14.58292825
			6 -d					1.039	39.32	104	-0.178	43.93					
D	Weldon Law	3rd floor fountain	1 - 250 mL	7.59	6.50	0.19	13.9	72.22	2583	330.9	1.301	199.5	88.91997	85.74139	24.932	107.7633	90.60150376
			1 -d					8.002	368.3	248.4	-0.101	18.75					
			2 - 250 mL					84.43	2642	268.9	1.146	236.2					
			3 - 250 mL					63.49	2436	244.5	1.028	180.1	90.51819	83.48112	28.58896	127.4319	89.60577457
			3 -d					6.02	402.4	174.6	-0.282	18.72					
			4 - 250 mL					46.25	2199	409.4	0.264	141.1					
			5 - 1000 m					75.43	4202	250.4	1.329	319.3	94.86279	92.54165	43.33067	120.6922	94.15283433
			5 -d					3.875	313.4	141.9	-0.275	18.67					
			6 - 1000 m					79.05	4363	229.9	1.984	344.3	96.28716	94.5267	50.89169	116.7339	96.36073192
			6 -d					2.935	238.8	112.9	-0.332	12.53					
E	D Building	5th	1 - 250 mL	7.39	0.31	0.10	14.1	2.499	248.3	201.4	-0.249	13.55	39.53581	20.74104	7.298908	-9.23695	28.10332103
			1 -d					1.511	196.8	186.7	-0.272	9.742					
			2 - 250 mL					2.603	253	195.2	-0.343	12.44					
			3 - 250 mL					2.859	258.8	156.9	-0.426	14.28	47.46415	26.39104	22.81708	10.0939	39.12464986
			3 -d					1.502	190.5	121.1	-0.383	8.693					
			4 - 250 mL					2.874	241.2	131.5	-0.445	11.05					
			5 - 1000 m					2.422	196.6	119.8	-0.419	13.93	33.44344	22.27874	-19.8664	11.93317	-20.67480258
			5 -d					1.612	152.8	143.6	-0.369	16.81					
			6 - 1000 m					1.814	147.4	98.4	-0.391	13.46	45.2591	24.83039	9.430894	-7.16113	17.01337296
			6 -d					0.993	110.8	89.12	-0.419	11.17					

Table B.4: Fountain investigation results – July 10/14, 2011

													% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	A building	1st floor main hallway	1 - 250 mL	7.68	0.15	0.06	17.1	2.271	342.5	176.2	-0.701	44.46	36.19551	36.11679	46.07264	14.55064	22.19973
			1 -d					1.449	218.8	95.02	-0.599	34.59					
			2 - 250 mL					2.983	505.2	120.6	-0.762	44.17					
			3 - 250 mL					2.814	318.8	473.4	-0.76	58.38	30.98792	30.05019	75.85551	15.65789	23.87804
			3 -d					1.942	223	114.3	-0.641	44.44					
			4 - 250 mL					2.128	326.6	158	-0.757	49.1					
			5 - 1000 m					2.424	271.2	479.5	-0.777	103	29.33168	18.65782	82.63816	10.81081	61.640777
			5 -d					1.713	220.6	83.25	-0.693	39.51					
			6 - 1000 m					3.339	248	150.3	-0.74	51.51	33.54298	21.85484	45.9481	4.054054	24.519511
			6 -d					2.219	193.8	81.24	-0.71	38.88					
B	J Building	main floor	1 - 250 mL	7.78	0.22	0.04	14.8	0.155	60.95	72.57	0.06	61.2	-5.16129	21.57506	13.02191	-211.667	8.7418301
			1 -d					0.163	47.8	63.12	0.187	55.85					
			2 - 250 mL					0.269	73.9	91.98	-0.059	66					
			3 - 250 mL					0.574	91.88	104.3	-0.056	74.25	71.25436	44.32956	31.35187	108.9286	22.10101
			3 -d					0.165	51.15	71.6	0.005	57.84					
			4 - 250 mL					0.249	68.44	88.18	-0.096	75.84					
			5 - 1000 m					0.392	75.65	91.22	-0.092	91.62	57.65306	48.19564	25.56457	71.73913	25.638507
			5 -d					0.166	39.19	67.9	-0.026	68.13					
			6 - 1000 m					0.191	56.53	80.39	-0.113	99.57	14.65969	44.61348	17.7634	67.25664	17.967259
			6 -d					0.163	31.31	66.11	-0.037	81.68					
C	Weldon Law	1st	1 - 250 mL	7.46	0.98	0.06	13.5	12.26	211.1	267.1	0.46	42.58	43.77651	24.25391	32.23512	-0.86957	45.232504
			1 -d					6.893	159.9	181	0.464	23.32					
			2 - 250 mL					11.11	236.3	166.5	0.45	31.07					
			3 - 250 mL					8.401	261.4	198.9	0.309	32.86	42.42352	19.43382	32.27753	-11.3269	39.896531
			3 -d					4.837	210.6	134.7	0.344	19.75					
			4 - 250 mL					5.903	264.2	156.3	0.326	24.74					
			5 - 1000 m					3.84	218	200.4	0.39	117.6	66.74479	21.33028	45.70858	77.17949	84.209184
			5 -d					1.277	171.5	108.8	0.089	18.57					
			6 - 1000 m					2.532	167.4	218.6	0.277	225.3	67.77251	31.72043	52.79048	73.2852	90.967599
			6 -d					0.816	114.3	103.2	0.074	20.35					
D	The link	1st, by tims	1 - 250 mL	10.25	0.23	0.04	15.5	0.12	4.761	172.7	0.332	12.98	31.66667	29.76265	98.48813	-25.6024	52.604006
			1 -d					0.082	3.344	2.611	0.417	6.152					
			2 - 250 mL					0.159	6.115	47.32	0.206	10.84					
			3 - 250 mL					0.086	7.155	31.2	0.154	6.634	-27.907	-12.2711	83.94551	-35.0649	23.605668
			3 -d					0.11	8.033	5.009	0.208	5.068					
			4 - 250 mL					0.108	7.007	85.99	0.071	10.24					
			5 - 1000 m					0.13	5.909	68.46	0.024	13.47	2.307692	4.789304	99.01402	-341.667	62.227171
			5 -d					0.127	5.626	0.675	0.106	5.088					
			6 - 1000 m					0.18	4.386	42.95	-0.017	12.22	71.66667	66.75787	-130.454	647.0588	44.558101
			6 -d					0.051	1.458	98.98	0.093	6.775					
E	The Link	1st , North end	1 - 250 mL	8.08	0.16	0.17	12.8	0.272	33.9	79.7	11.47	1.9	-20.5882	33.42183	6.524467	48.70968	-35.68421
			1 -d					0.328	22.57	74.5	5.883	2.578					
			2 - 250 mL					0.236	35.99	70.63	9.795	1.694					
			3 - 250 mL					0.167	32.57	68.52	9.508	1.835	41.91617	27.90912	-0.78809	53.60749	15.531335
			3 -d					0.097	23.48	69.06	4.411	1.55					
			4 - 250 mL					0.209	31.73	105.3	8.677	6.643					
			5 - 1000 m					0.148	29.15	83.36	8.332	3.156	-35.1351	24.28816	24.42418	53.01248	-1.61597
			5 -d					0.2	22.07	63	3.915	3.207					
			6 - 1000 m					0.139	26.97	105	7.147	3.482	23.74101	31.92436	33.84762	49.67119	41.987364
			6 -d					0.106	18.36	69.46	3.597	2.02					
F	The Link	2nd, North end	1 - 250 mL	7.5	0.25	0.02	15.8	1.794	570.4	186.5	0.052	4.167	56.63322	19.14446	25.41555	155.7692	84.521238
			1 -d					0.778	461.2	139.1	-0.029	0.645					
			2 - 250 mL					1.907	669.1	246.1	0.042	6.886					
			3 - 250 mL					2.407	755.4	775.9	0.027	72.89	66.09888	25.97299	77.21356	133.3333	99.506105
			3 -d					0.816	559.2	176.8	-0.009	0.36					
			4 - 250 mL					2.194	825.3	267.4	0.017	13.43					
			5 - 1000 m					2.41	899.1	189.1	0.045	2.077	61.78423	19.07463	10.04759	208.8889	100.24073
			5 -d					0.921	727.6	170.1	-0.049	-0.005					
			6 - 1000 m					2.16	809.4	335.8	0.065	19.42	60.41667	18.77934	47.70697	164.6154	102.31205
			6 -d					0.855	657.4	175.6	-0.042	-0.449					

Table B.5: Fountain investigation results – July 28, 2011

													% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	D-Building	2nd floor	1 - 250 mL	7.53	0.12	0.49	20.7	0.818	51.44	137.8	-5.916	17.53	60.51345	28.81026	15.16691	2.789047	21.33485454
			1 -d					0.323	36.62	116.9	-5.751	13.79					
			2 - 250 mL					0.168	24.4	88.63	-6.292	20.46					
			3 - 250 mL					1.913	21.67	85.56	-6.271	20.53	86.72243	21.96585	15.88359	5.342051	2.776424744
			3 -d					0.254	16.91	71.97	-5.936	19.96					
			4 - 250 mL					0.574	23.45	82.68	-6.364	22.23					
			5 - 1000 m					0.095	20.38	74.29	-6.33	24.33	-146.316	27.23258	9.987885	4.660348	10.19317715
			5 -d					0.234	14.83	66.87	-6.035	21.85					
			6 - 1000 m					0.286	20.69	99.09	-6.394	29.23	38.46154	26.63122	28.69109	5.270566	9.613410879
			6 -d					0.176	15.18	70.66	-6.057	26.42					
B	Q-Building	Entrance	1 - 250 mL		3.36	0.03		17.88	1554	1062	79.14	25.28	20.0783	15.05792	13.06026	78.8097	70.1028481
			1 -d					14.29	1320	923.3	16.77	7.558					
			2 - 250 mL					15.45	1258	863.9	48.61	15.54					
			3 - 250 mL					12.37	1184	805.7	26.28	12.16	70.26677	47.9223	27.50403	119.1553	87.49177632
			3 -d					3.678	616.6	584.1	-5.034	1.521					
			4 - 250 mL					12.03	1112	1358	22.16	90.93					
			5 - 1000 m					11.47	1120	727.2	21.66	10.48	59.31125	37.19643	20.22827	124.0813	71.47900763
			5 -d					4.667	703.4	580.1	-5.216	2.989					
			6 - 1000 m					12.18	1133	721.5	25.16	13.27	66.40394	42.43601	24.86486	120.787	54.44611907
			6 -d					4.092	652.2	542.1	-5.23	6.045					
C	Chemistry	3rd Floor	1 - 250 mL		1.65	0.64		7.599	174.4	160.8	-5.831	9.372	59.02092	22.19037	39.52114	-1.42343	47.65258216
			1 -d					3.114	135.7	97.25	-5.914	4.906					
			2 - 250 mL					6.057	185.8	89.98	-6.346	0.345					
			3 - 250 mL					4.664	168.9	98.58	-6.236	2.522	66.80961	23.86027	18.58389	3.367543	-21.2926249
			3 -d					1.548	128.6	80.26	-6.026	3.059					
			4 - 250 mL					4.165	150.6	391.2	-6.397	5.954					
			5 - 1000 m					2.383	121.8	83.95	-6.23	2.21	59.50483	30.4023	13.49613	0.979133	-39.04977376
			5 -d					0.965	84.77	72.62	-6.169	3.073					
			6 - 1000 m					1.766	96.32	83.18	-6.331	2.001	55.83239	15.58347	9.232989	1.311009	-247.2263868
			6 -d					0.78	81.31	75.5	-6.248	6.948					
D	Dentistry	Front of biulding	1 - 250 mL		1.15	0.5		180.3	6759	465	-4.733	401.7	99.25125	96.5557	73.87097	-33.6784	98.90465522
			1 -d					1.35	232.8	121.5	-6.327	4.4					
			2 - 250 mL					8.811	651	208.7	-6.569	25.33					
			3 - 250 mL					3.815	345	113.6	-6.612	12.91	78.03408	58.4058	22.87852	2.828191	53.90395043
			3 -d					0.838	143.5	87.61	-6.425	5.951					
			4 - 250 mL					2.786	258	153.8	-6.669	14.25					
			5 - 1000 m					2.578	175.6	142.7	-6.702	15.71	74.28239	61.67426	49.5445	5.207401	30.49013367
			5 -d					0.663	67.3	72	-6.353	10.92					
			6 - 1000 m					1.005	87.49	198.6	-6.635	16.33	59.60199	44.46222	64.74824	3.767898	31.47581139
			6 -d					0.406	48.59	70.01	-6.385	11.19					

Table B.6: Fountain investigation results – August 4, 2011

														% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	TOC/DOC (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	Weldon Law - 1st floor	24 hr stag	1 - 250 mL	7.61	0.33	0.28	14.6	12.95	194.6	176.3	0.452	23.63	1.701	39.82239	22.148	10.20987	9.070796	32.92424884
			1 -d					7.793	151.5	158.3	0.411	15.85	1.665					
			2 - 250 mL					10.78	255.3	141.3	0.24	19.68						
			3 - 250 mL					7.296	258.9	139.4	0.388	18.01	1.57	28.39912	20.16222	4.591105	0.515464	27.92892837
			3 -d					5.224	206.7	133	0.386	12.98	1.667					
			4 - 250 mL					5.874	258.4	134.7	0.324	20.18						
			5 - 1000 m					4.175	201.8	109.5	0.346	28.94	1.611	26.2515	22.24975	13.56164	21.96532	28.95646164
			5 -d					3.079	156.9	94.65	0.27	20.56	1.614					
			6 - 1000 m					2.25	143.9	82.2	0.324	39.58	1.81	-5.28889	25.36484	2.895377	19.44444	37.51894896
			6 -d					2.369	107.4	79.82	0.261	24.73	1.765					
			f					0.869	82.99	65.4	0.448	19.03						
B	Weldon Law - 1st floor	5 minute stag	1 - 250 mL	7.47	0.45	0.6	14.1	1.644	100.8	92.29	1.433	31.09	1.805	-47.9927	24.79167	12.66659	76.41312	57.63911225
			1 -d					2.433	75.81	80.6	0.338	13.17	1.808					
			2 - 250 mL					1.294	93.08	74.82	0.265	18.29						
			3 - 250 mL					0.988	104.3	75.55	0.221	18.05	1.766	-63.9676	29.81783	3.481138	-21.267	27.25761773
			3 -d					1.62	73.2	72.92	0.268	13.13	1.836					
			4 - 250 mL					6.207	109.1	81.27	0.303	18.91						
			5 - 1000 m					1.33	107.3	71.46	0.187	21.98	1.758	8.045113	19.5713	9.445844	-24.0642	41.94722475
			5 -d					1.223	86.3	64.71	0.232	12.76	1.888					
			f					1.059	79.08	62.14	0.154	19.96						
C	Weldon Law - 1st floor	30 min stag	1 - 250 mL	7.66	0.47	0.53	14.3	1.561	96.91	319.1	0.409	31.57	1.737	23.76682	23.52698	68.86556	15.40342	51.18783655
			1 -d					1.19	74.11	99.35	0.346	15.41	1.889					
			2 - 250 mL					1.686	106.5	71.19	0.218	17.09						
			3 - 250 mL					1.314	130.2	77.05	0.173	17.18	1.753	48.78234	30.01536	13.49773	-39.8844	43.13154831
			3 -d					0.673	91.12	66.65	0.242	9.77	1.789					
			4 - 250 mL					1.473	139.1	88.95	0.275	19.67						
			5 - 1000 m					1.01	124.5	74.3	0.167	15.86	1.728	-15.7426	20.21687	2.409152	-20.3593	28.62547289
			5 -d					1.169	99.33	72.51	0.201	11.32	1.97					
			f					1.474	73.38	60.25	0.113	20.64						
D	Weldon Law - 1st floor	1 hr stag	1 - 250 mL	7.64	1.18	0.58	14.8	1.439	93.14	102.6	0.136	20.1	1.728	-89.7151	22.76143	13.8694	-237.5	39.00497512
			1 -d					2.73	71.94	88.37	0.459	12.26	1.864					
			2 - 250 mL					3.578	119.2	76.96	1.047	18.19						
			3 - 250 mL					2.017	146.1	81.99	0.295	16.17	1.657	5.999008	21.35524	-4.90304	17.9661	28.38589981
			3 -d					1.896	114.9	86.01	0.242	11.58	1.702					
			4 - 250 mL					1.489	143.3	78.33	0.19	13.64						
			5 - 1000 m					1.056	131.9	74.32	0.159	13.82	1.663	100	100	100	100	100
			5 -d										1.94					
			f					1.604	76.98	64.11	0.363	34.13						
E	Weldon Law - 1st floor	6 hr stag	1 - 250 mL	7.64	-	-	13.7	5.925	140.1	153.1	0.246	22.79	1.733	45.5865	24.69665	21.48922	-5.28455	49.67090829
			1 -d					3.224	105.5	120.2	0.259	11.47	2.106					
			2 - 250 mL					4.708	168.9	106.6	0.212	21.46						
			3 - 250 mL					3.971	202.2	106.6	0.449	25.04	1.691	51.17099	22.30465	18.20826	31.40312	59.38498403
			3 -d					1.939	157.1	87.19	0.308	10.17	1.889					
			4 - 250 mL					2.691	198	98.15	0.208	23.48						
			5 - 1000 m					1.673	164.2	83.86	0.197	21.67	1.754	39.03168	20.03654	14.38111	-29.4416	39.77849562
			5 -d					1.02	131.3	71.8	0.255	13.05	1.942					
			f					3.877	91.44	59.05	0.432	57.46						

Table B.7: Fountain investigation results – August 11, 2011

																	% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	TOC/DOC (mg/L)	Chloride (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	D bldg	5th floor	1 - 250 mL	7.44	1.09	0.11	12.4	3.443	218.5	249.2	-0.153	69.2	1.997				59.10543	21.05263	27.56822	-148.366	63.9017341
			1 -d					1.408	172.5	180.5	-0.38	24.98	3.027								
			2 - 250 mL					3.208	222.8	129.8	-0.234	47.59		5.805	0.4050	5.1150					
			3 - 250 mL					4.315	234.2	177.1	-0.051	53.08	1.733				63.96292	25.14944	28.4585	-864.706	75.18839488
			3 -d					1.555	175.3	126.7	-0.492	13.17	2.219								
			4 - 250 mL					4.321	222.6	139.3	-0.341	50.65		6.182	0.2280	6.3040					
			5 - 1000 mL					4.569	193.6	578.8	0.039	88.57	1.753				65.638	27.16942	81.70352	1405.128	23.26973016
			5 -d					1.57	141	105.9	-0.509	67.96	1.985								
			6 - 1000 mL					3.882	159.2	254.4	0.192	87.3	1.691				60.66461	29.77387	63.72248	342.1875	49.43871707
			6 -d					1.527	111.8	92.29	-0.465	44.14	2.015								
B	Chemistry-3rd floor	16 hr stag	1 - 250 mL	7.69	0.29	0.56	11.8	6.639	143.7	109.3	-0.529	4.942	1.722				44.0729	17.119	-1.73833	1.512287	-39.55888304
			1 -d					3.713	119.1	111.2	-0.521	6.897	2.083								
			2 - 250 mL					5.91	159	131.2	-0.568	10.54		6.646	0.1650	6.4280					
			3 - 250 mL					4.73	154.8	85.12	-0.563	6.379	1.759				44.6723	18.02326	3.218985	0.71048	0.971939175
			3 -d					2.617	126.9	82.38	-0.559	6.317	1.912								
			4 - 250 mL					3.742	139.7	83.84	-0.56	6.133		6.393	0.2470	6.1430					
			5 - 1000 mL					2.923	117.6	128.5	-0.388	16.4	1.939				57.68047	21.81122	39.85992	-44.8454	57.5
			5 -d					1.237	91.95	77.28	-0.562	6.97	2.164								
			6 - 1000 mL					1.628	89.95	76.71	-0.569	8.443	1.839				49.5086	15.14175	-8.14757	0.351494	0.532985905
			6 -d					0.822	76.33	82.96	-0.567	8.398									
			Bf					4.561	60.64	305.6	0.515	63.73	2.088								
C	Chemistry-3rd floor	10 min stag	1 - 250 mL	7.11	0.40	0.68	12.1	1.975	66.68	79.03	-0.272	7.808	1.735				71.44304	24.11518	2.745793	-102.574	-16.62397541
			1 -d					0.564	50.6	76.86	-0.551	9.106	1.691								
			2 - 250 mL											6.682	0.3270	6.4730					
			3 - 250 mL					1.742	75.89	109.8	-0.142	12.68	1.801				75.54535	23.92937	37.64117	-299.296	35.28391167
			3 -d					0.426	57.73	68.47	-0.567	8.206	1.876								
			4 - 250 mL					1.773	75.31	95.8	-0.311	10.41		6.888	0.3030	6.8760					
			5 - 1000 mL					1.824	71.69	168	-0.429	13.07	1.75				72.53289	16.34817	59.10119	-39.627	30.45906656
			5 -d					0.501	59.97	68.71	-0.599	9.089	1.72								
			Cf					2.537	54.66	182.3	0.314	13.91									
D	Chemistry-3rd floor	30 min stag	1 - 250 mL	7.61	0.54	0.53	11.3	1.957	68.08	169.1	-0.277	18.79	1.797				76.59683	22.41481	49.46777	-101.805	88.79191059
			1 -d					0.458	52.82	85.45	-0.559	2.106	1.857								
			2 - 250 mL					1.816	82.09	233.2	-0.035	13.99		6.893	0.3130	6.6080					
			3 - 250 mL					1.86	87.95	139.8	-0.294	19.13	1.977				68.22581	19.84082	37.63233	-104.762	67.04129639
			3 -d					0.591	70.5	87.19	-0.602	6.305	1.982								
			4 - 250 mL					1.522	85.62	164.6	-0.417	12.88		7.193	0.2860	6.8270					
			5 - 1000 mL					1.207	78.05	165.9	-0.523	16.75					42.41922	30.78796	35.74442	-12.2371	48.59104478
			Df					0.695	54.02	106.6	-0.587	8.611									
E	Chemistry-3rd floor	1 hr stag	1 - 250 mL	7.61	0.37	0.63	10	1.186	74.04	156	-0.605	20	1.789				64.16526	22.51486	52.14103	-1.15702	84.275
			1 -d					0.425	57.37	74.66	-0.612	3.145	1.789								
			2 - 250 mL					1.295	89.13	76.35	-0.617	2.579		7.063	0.2550	6.7900					
			3 - 250 mL					1.283	95.41	116.7	-0.583	8.538	1.683				53.39049	21.8845	35.8012	-1.71527	60.55282268
			3 -d					0.598	74.53	74.92	-0.593	3.368	1.745								
			4 - 250 mL					1.156	91.09	123.3	-0.618	9.174		6.682	0.2640	6.6120					
			5 - 1000 mL					1.323	81.92	235.8	-0.612	41.36	1.752				68.78307	19.64111	70.98813	3.267974	92.19777563
			5 -d					0.413	65.83	68.41	-0.592	3.227	1.718								
			Ef					1.465	55.41	71.07	0.404	3.76									
F	Chemistry-3rd floor	6 hr stag	1 - 250 mL	7.62	0.42	0.47	12.3	4.818	114.1	97.74	1.549	3.836	1.718				59.56829	21.70026	11.8273	134.9903	17.10114703
			1 -d					1.948	89.34	86.18	-0.542	3.18	1.716								
			2 - 250 mL					3.552	130.4	80.37	-0.542	2.488									
			3 - 250 mL					2.898	131.3	78.39	-0.552	2.565	1.75				49.4824	18.12643	7.335119	-2.35507	-34.26900585
			3 -d					1.464	107.5	72.64	-0.565	3.444	1.723								
			4 - 250 mL					2.391	121.6	79.12	-0.552	3.171									
			5 - 1000 mL					1.947	102.7	75.85	0.198	3.73									

Table B.8: Fountain investigation results – August 18, 2011

																	% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	TOC/DOC (mg/L)	Chloride (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	Chase	3rd	1 - 250 mL	7.77	0.14	0.05	13.6	6.028	195.1	805.7	-0.18	15.57	1.677				55.59058	33.26499	-0.33511	29.44444	26.39691715
			1 -d					2.677	130.2	808.4	-0.127	11.46	1.609								
			2 - 250 mL					5.367	208.1	736.3	-0.205	14.63		7.825	0.2270	7.4900					
			3 - 250 mL					8.107	212.3	598.6	-0.181	13.97	1.516				47.46515	25.15309	-0.53458	17.12707	33.35003579
			3 -d					4.259	158.9	601.8	-0.15	9.311	1.518								
			4 - 250 mL					8.094	200.4	549.6	-0.202	13.05		7.894	0.2060	7.5930					
			5 - 1000 m					6.526	176.3	480.9	-0.193	15.65	1.589				49.26448	30.62961	10.91703	34.19689	30.67092652
			5 -d					3.311	122.3	428.4	-0.127	10.85	1.589								
			6 - 1000 m					5.609	128.3	439.2	-0.15	14.63	1.747				60.09984	33.34373	12.40893	-11.3333	27.13602187
			6 -d					2.238	85.52	384.7	-0.167	10.66	1.635								
B	Weldon	1st	1 - 250 mL	7.52	0.32	0.17	11.3	9.419	186	234.6	-0.19	11.86	1.771				38.2737	15.75269	10.1023	24.21053	56.81281619
			1 -d					5.814	156.7	210.9	-0.144	5.122	1.657								
			2 - 250 mL					7.942	210.5	143.5	-0.187	5.127		7.82	0.1060	7.7740					
			3 - 250 mL					5.611	235.2	143.4	-0.182	5.043	1.55				38.44235	20.45068	10.59972	13.18681	37.93376958
			3 -d					3.454	187.1	128.2	-0.158	3.13	1.522								
			4 - 250 mL					4.258	235.6	139.2	-0.215	3.738		8.602	0.1410	8.5240					
			5 - 1000 m					2.585	193.8	144.6	-0.131	13.81	1.575								
			5 -d										1.474								
			6 - 1000 m					1.65	152.4	96.42	-0.135	19.31	1.74				42.90909	22.90026	12.55963	22.22222	46.40082859
			6 -d					0.942	117.5	84.31	-0.105	10.35	1.676								
C	Weldon	2nd	1 - 250 mL	7.62	0.17	0.17	15	1.223	148.6	127.8	-0.202	10.67	1.739				33.36059	21.46703	14.08451	40.59406	32.24929709
			1 -d					0.815	116.7	109.8	-0.12	7.229	1.658								
			2 - 250 mL					2.042	153.4	111.2	-0.192	15.09		9.068	0.3100	9.1850					
			3 - 250 mL					2.45	158	85.54	-0.184	13	1.704				38.65306	21.51899	12.28665	22.82609	39.99230769
			3 -d					1.503	124	75.03	-0.142	7.801	1.644								
			4 - 250 mL					2.524	153.2	86.06	-0.191	13.38		8.363	0.2510	8.5800					
			5 - 1000 m					2.041	121.9	82.18	-0.201	13.64	1.74								
			5 -d																		
			6 - 1000 m					1.378	89.9	74.04	-0.217	13.36	1.749				35.84906	18.79867	11.99352	49.76959	22.08083832
			6 -d					0.884	73	65.16	-0.109	10.41	1.753								
D	Weldon	3rd	1 - 250 mL	7.38	0.94	0.04	13.7	27.19	998.8	460.8	0.615	51.72	1.649				67.83008	56.06728	6.684028	120.813	83.32173241
			1 -d					8.747	438.8	430	-0.128	8.626	1.613								
			2 - 250 mL					23.39	1039	382.3	0.222	44.51		8.375	0.0410	8.4100					
			3 - 250 mL					23.09	1127	435.9	0.951	54	1.705				67.66566	45.23514	21.1287	110.8307	85.21481481
			3 -d					7.466	617.2	343.8	-0.103	7.984	1.663								
			4 - 250 mL					19.69	1130	333.2	0.229	45.99		7.87	0.0200	8.0160					
			5 - 1000 m					20.8	1250	266.5	0.286	70.41	1.676				78.59135	61.088	13.77111	159.4406	90.77829854
			5 -d					4.453	486.4	229.8	-0.17	6.493	1.656								
			6 - 1000 m					22.91	1184	208.3	0.524	90.44	1.927				85.63073	71.55405	18.96303	126.145	89.88168952
			6 -d					3.292	336.8	168.8	-0.137	9.151	1.68								
E	Weldon	4th	1 - 250 mL	7.47	0.15	0	12.7	10.24	395	191.7	-0.141	11.74	1.682				35.2832	17.44304	8.972353	-10.6383	24.07155026
			1 -d					6.627	326.1	174.5	-0.156	8.914	1.698								
			2 - 250 mL					9.187	421.1	145.2	-0.128	11.21		7.937	0.1760	8.0790					
			3 - 250 mL					8.057	419.5	138.5	-0.14	9.503	1.697				37.49535	17.87843	9.530686	-23.5714	26.83363148
			3 -d					5.036	344.5	125.3	-0.173	6.953	1.72								
			4 - 250 mL					7.002	394.7	131.1	-0.148	8.245		7.844	0.2240	8.1330					
			5 - 1000 m					5.84	340.6	114.2	0.025	10.46	1.59				48.59589	22.60716	12.47811	792	37.66730402
			5 -d					3.002	263.6	99.95	-0.173	6.52	1.614								
			6 - 1000 m					3.713	263.8	99.39	-0.114	25.53	1.605				41.01804	16.30023	10.24248	-21.9298	37.95534665
			6 -d					2.19	220.8	89.21	-0.139	15.84	1.622								

Table B.9: Fountain Investigation Results – August 24, 2011

														% Particulate				
	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)	TOC/DOC (mg/L)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (mg/L)
A	Chemistry	1st	1 - 250 mL	7.43	0.20	0.04	11.7	0.008	201.2	42.93	-0.638	1.725	1.184					
			1 -d					0.21	159.1	52.3	-0.553	2.6	1.359					
			2 - 250 mL					0.018	201.8	49.74	-0.643	2.928						
			3 - 250 mL					0.016	173.7	31.42	-0.632	5.603	1.139					
			3 -d					0.093	151.7	41.46	-0.598	2.499	1.306					
			4 - 250 mL					0.003	150	5.136	-0.629	-0.175						
			5 - 1000 m					0.016	106.1	20.39	-0.636	2.402	1.049					
			5 -d					0.175	94.35	33.69	-0.556	1.95						
			6 - 1000 m					0.029	67.94	4.241	-0.638	0.37	1.153					
			6 -d					0.054	53.2	12.23	-0.605	1.172	1.54					
B	Chemistry	2nd	1 - 250 mL	7.51	0.17	0.4	14.1	3.731	115	107.2	-0.534	1.63	1.826	52.47923	23.63478	3.731343	-9.92509	44.04907975
			1 -d					1.773	87.82	103.2	-0.587	0.912	1.912					
			2 - 250 mL					3.287	121.1	92.26	-0.536	1.149						
			3 - 250 mL					2.531	118.5	89.04	-0.601	1.287	1.955	45.31806	17.26582	-3.05481	1.164725	8.78010878
			3 -d					1.384	98.04	91.76	-0.594	1.174	1.876					
			4 - 250 mL					2.034	107.7	86.37	-0.6	1.8						
			5 - 1000 m					1.325	85.76	106.3	-0.577	6.242	2.105	50.41509	19.96269	23.76294	-0.69324	70.95482217
			5 -d					0.657	68.64	81.04	-0.581	1.813	1.915					
			6 - 1000 m					0.941	67.21	75.73	-0.571	2.167	1.838	57.5983	17.43788	-9.37541	-6.1296	24.68850946
			6 -d					0.399	55.49	82.83	-0.606	1.632	1.947					
C	Chemistry	4th	1 - 250 mL	7.54	0.25	0.22	13	10.36	163.9	121	0.087	0.537	1.968	60.40541	18.24283	-4.87603	754.023	-110.9869646
			1 -d					4.102	134	126.9	-0.569	1.133	2.249					
			2 - 250 mL					5.632	176	97.03	-0.333	-0.184						
			3 - 250 mL					4.625	177.8	96.64	-0.461	-0.164	1.816	40.3027	19.12261	8.267798	-28.4165	128.0487805
			3 -d					2.761	143.8	88.65	-0.592	0.046	1.887					
			4 - 250 mL					3.609	166.6	97.71	-0.337	-0.577						
			5 - 1000 m					2.542	138.1	89.82	-0.179	-0.189	1.736	45.16129	15.20637	8.3723	110.0559	1220.10582
			5 -d					1.394	117.1	82.3	0.018	2.117	1.948					
			6 - 1000 m					1.557	106	82.42	0.205	0.742	1.832	54.91329	18.5566	9.876244	143.9024	50.94339623
			6 -d					0.702	86.33	74.28	-0.09	0.364	1.953					

Table B.10: Fountain investigation results – September 12, 2011

Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)	TOC/DOC (mg/L)	Chloride (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)
D-building	4th floor	1 - 250 mL	7.72	0.19	0.42	12.9	0.439	84.89	222.2	-0.147	11.39				
		1 -d					1.137	65.12	169.5	-0.15	5.263				
		2 - 250 mL					0.472	93.5	138.6	-0.169	9.076		9.734	0.3310	8.0900
		3 - 250 mL					0.904	98.71	415.6	-0.174	61.35				
		3 -d					0.599	83.5	115.4	-0.148	6.482				
		4 - 250 mL					0.825	92.53	141.6	-0.208	11.96		9.558	0.2960	8.4988
		5 - 1000 m					0.701	73.94	112.6	-0.214	12.7				
		5 -d					0.797	56.33	110.2	-0.163	8.989				
		6 - 1000 m					0.791	57.1	115.4	-0.228	14.9				
		6 -d					0.409	41.77	102.7	-0.185	9.556				
D-building	5th floor	1 - 250 mL	7.63	0.28	0.16	12.5	2.689	216.8	227.6	-0.054	10.95				
		1 -d					1.564	169.7	200.1	-0.142	7.358				
		2 - 250 mL					2.926	223.6	170.8	0.364	11.43		10.342	0.2480	9.7820
		3 - 250 mL					3.002	232.2	238.3	-0.053	10.14				
		3 -d					1.647	184.9	145.5	-0.129	6.544				
		4 - 250 mL					3.297	222.9	157.7	0.078	11.19		9.94	0.2570	9.2650
		5 - 1000 m					2.914	182	117.8	0.192	9.788				
		5 -d								-0.14	7.865				
		6 - 1000 m					2.355	134.6	211.9	0.074	18.91				
		6 -d								-0.178	8.832				

Table B.11: Fountain investigation results – September 15/16, 2011

	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)	Chloride (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)
A	Weldon Law - 1st floor	3 hr stag	1 - 250 mL	7.65	0.58	0.5	13.1	2.67	122.3	388.5	0.28	57.87			
			1 -d					1.437	90.67	87.66	0.306	20.25			
			2 - 250 mL					2.563	148.3	131	0.323	35.14			
			3 - 250 mL					2.077	167.7	82.43	0.381	25.71			
			3 -d					1.104	134.6	76.72	0.384	17.19			
			4 - 250 mL					1.292	166.1	78.68	0.238	24.73			
			5 - 1000 m					0.749	136.6	161.3	0.24	52.58			
			5 -d					0.193	105.2	79.19	0.328	15.07			
			6 - 1000 m					0.345	105.9	62.87	0.199	16.28			
			f					0.109	97.88	59.11	0.171	13.03			
B	Weldon Law - 1st floor	16 hr stag	1 - 250 mL	7.69	0.12	0.43	12.5	6.515	155.8	129.9	1.252	13.6			
			1 -d					4.061	121.2	116.8	0.447	8.824			
			2 - 250 mL					5.205	176.6	89.21	0.219	8.524	9.546	0.2930	8.6290
			3 - 250 mL					3.705	190.1	117.4	0.207	11.13			
			3 -d					2.3	160.6	96.52	0.248	7.636			
			4 - 250 mL					2.586	191.8	166.8	0.145	11.55	11.104	0.2320	10.1810
			5 - 1000 m					1.14	161.8	145.4	0.171	19.8	10.848	0.2650	10.0510
			5 -d					0.567	127.6	78.25	0.244	8.124			
			6 - 1000 m					0.971	130.4	75.91	0.207	15.83			
			6 - d					0.094	101.7	68.7	0.237	10.35			
			f					0.194	88.61	66.34	0.809	18.58			
C	Weldon Law - 1st floor	1 hr stag	1 - 250 mL	7.65	0.17	0.42	11.8	0.828	101	90.69	0.392	17.53			
			1 -d					0.311	79.56	82.65	0.469	13.23			
			2 - 250 mL					1.073	122.1	87.86	0.241	17.73	10.462	0.3570	9.9210
			3 - 250 mL					0.828	138.6	107.4	0.221	16.89			
			3 -d					0.4	112.8	72.29	0.315	43.28			
			4 - 250 mL					1.057	143.3	89.62	0.19	17.93	10.504	0.3350	9.8070
			5 - 1000 m					0.458	125.7	78.45	0.244	14.35	9.802	0.3510	9.4600
			5 -d					-0.043	101.8	63.4	0.282	11.58			
			f					-0.075	76.85	104.6	0.153	14.12			
D	Weldon Law - 1st floor	6 hr stag	1 - 250 mL	7.55	0.17	0.31	12.7	3.774	124.5	164.6	0.952	19.34			
			1 -d					2.191	99.95	107.5	0.483	8.687			
			2 - 250 mL					3.24	143.4	127.9	0.243	14.62	8.338	0.2430	8.1500
			3 - 250 mL					2.405	169.5	81.8	0.206	8.565			
			3 -d					1.396	142.4	73.52	0.258	5.889			
			4 - 250 mL					1.798	172.9	81.93	0.249	7.773	10.325	0.3420	9.7660
			5 - 1000 m					0.79	146.6	77.84	0.225	24.91	10.217	0.3390	9.6920
			5 -d					0.266	118.8	67.72	0.266	15.57			

Table B12: Fountain investigation results – November 18, 2011

Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)	Chloride (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)
Weldon Law - 1st floor	20 hr stag	1 - 250 mL	7.57	0.29	0.26	11.2	10.35	201.8	150.3	0.484	9.187			
		1 -d					7.303	149.5	127.6	1.185	7.033			
		2 - 250 mL					8.696	228.7	134.3	0.3	8.491	9.497	0.4330	7.8680
		3 - 250 mL					5.583	252.4	139.9	0.264	7.999			
		3 -d					4.029	202.8	125.9	0.367	5.789			
		4 - 250 mL					4.266	245.3	136	0.213	9.001	9.586	0.2480	8.4890
		5 - 1000 m					2.195	196.6	192	0.182	22.65			
		5 -d					1.906	157.2	115.4	1.144	9.615	9.658	0.291	9.068
		6 - 1000 m					1.009	142	181.2	0.154	18.77			
		6 - d					0.764	117.3	118.7	0.76	10.28			
		f					0.472	108.7	132.4	0.206	15.61			
Weldon Law - 1st floor	3 hr stag	1 - 250 mL	-	0.23	0.27	-	3.516	154.7	189.5	0.162	16.22			
		1 -d					2.631	131	154.3	0.283	10.85			
		2 - 250 mL					3.255	174.5	158.4	0.131	15.99	9.623	0.0000	9.2410
		3 - 250 mL					2.621	208.5	142.2	0.191	10.12			
		3 -d					1.817	169.9	125.7	0.185	8.352			
		4 - 250 mL					2.016	218.1	137.2	0.115	11.29	9.48	0.2530	9.0780
		5 - 1000 m					1.33	188.3	159.8	0.172	16.64			
		f					0.587	115	124.3	0.142	12.31			
Weldon Law - 1st floor	20 hr stag	1 - 250 mL	7.49	0.18	0.26	11.2	11.44	216.8	225.1	0.114	13.59			
		1 -d					8.756	187.3	173.4	0.33	8.295			
		2 - 250 mL					9.63	243.3	214.5	0.163	17.22	19.127	0.3940	17.0040
		3 - 250 mL					7.372	275.1	183.4	0.13	13.8			
		3 -d					5.294	220	135.2	0.197	7.564			
		4 - 250 mL					5.073	259.6	203.5	0.115	33.94	57.714	0.8350	49.9100
		5 - 1000 m					2.525	212.1	179.1	0.093	20.51			
		f					0.413	101	124.4	0.083	25.69			
Weldon Law - 1st floor	6 hr stag	1 - 250 mL	7.7	0.20	0.33	14.1	5.147	159.8	161.1	0.088	21.87			
		1 -d					4.267	132.9	144.9	0.203	20.41			
		2 - 250 mL					4.632	194.4	130.5	0.079	21.76	59.491	1.0700	43.8450
		3 - 250 mL					3.549	228.4	132.1	0.217	19.65			
		3 -d					2.687	194	123.9	0.259	16.66			
		4 - 250 mL					2.63	230.3	194.6	0.113	44.49	59.929	1.6090	44.6090
		5 - 1000 m					5.445	183.3	128.4	0.132	19.66			
		5 -d					1.548	139.8	104.3	0.186	14.64			
		6 - 1000mL					0.775	132.6	104.8	0.411	17.41			
		f					0.422	98.88	101.6	0.081	18.37			

Table B.13: Fountain investigation results – January 16, 2012

	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)
A	Weldon Law - 1st floor	48 hr stag	1 - 125 mL					22.3	204.5	238.7	0.112	15.87
			2 - 125 mL					24.12	203.8	162.3	0.201	18.45
			3 - 125 mL					22.6	231.7	160.2	0.326	21.21
			4 - 125 mL					20.21	249.6	163.1	0.374	21.92
			5 - 125 mL					17.31	258.4	162.2	0.297	20.64
			6 - 125 mL					21.17	259.7	161.3	2.078	18.47
			7 - 125 mL					12.47	259.4	160.6	0.238	17.24
			8 - 125 mL					10.22	248.5	156.7	0.543	16.18
			9 - 250 mL					7.723	226.6	147.4	0.169	17.48
			10 - 250 mL					5.446	191.7	133.4	0.204	20.34
			11 - 250 mL					3.983	162.2	125.5	0.169	23.66
			12 - 250 mL					2.75	138.5	118.3	0.172	27.27
			13 - 250 mL					2.055	118	129	0.062	43.48
			14 - 250 mL					1.516	105.6	109.6	0.096	33.05
			15 - 250 mL					1.288	96.12	105.9	0.125	36.15
			16 - 250 mL					0.966	88.4	104.6	0.126	37.32

Table B.14: Fountain investigation results – March 1, 2012

	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)
A	Weldon Law - 1st floor	16 hr stag	1 - 125 mL					13.34	233.7	199.9	0.099	8.52
			2 - 125 mL					13.63	231.4	143.1	0.048	8.157
			3 - 125 mL					11.87	254.2	145.4	0.039	8.075
			4 - 125 mL					9.864	269.7	145.4	0.056	8.315
			5 - 125 mL					8.521	272.3	145.3	0.018	7.662
			6 - 125 mL					6.141	272.9	138.2	0.022	7.82
			7 - 250 mL					4.927	261.8	142.5	0.011	8.27
			8 - 250 mL					3.452	226.6	128.2	0.052	9.352
			9 - 250 mL					4.048	198.5	213.5	0.056	22.81
			10 - 250 mL					2.028	165.6	124.4	0.008	14.03
			11 - 250 mL					1.373	145.5	111.1	0.047	12.31
			12 - 250 mL					2.294	125.5	108	0.166	11.94
			13 - 250 mL					0.774	109.9	104.7	0.002	11.6
B	Weldon Law - 3rd floor	16 hr stag	1 - 250 mL					37.36	778.1	557.3	0.162	11.7
			2 - 250 mL					32.2	887.6	356.5	0.097	11.03
			3 - 250 mL					26.9	871.5	866.8	0.073	46.34
			4 - 250 mL					20.31	822.4	318	0.05	11.82
			5 - 250 mL					17.7	745.6	294.7	0.067	14.15
			6 - 250 mL					14.5	641.5	260.8	0.035	13.9
			7 - 250 mL					10.58	525.1	271.7	0.014	28.03
			8 - 250 mL					9.749	476.4	216.9	0.099	14.21

Table B.15: Fountain investigation results – May 28/29, 2012

	Building	Location		pH	Turbidity (NTU)	Free Chlorine (mg/L)	Temperature ('C)	Lead (ug/L)	Copper (ug/L)	Zinc (ug/L)	Tin (ug/L)	Iron (ug/L)	Aluminum
A	Weldon Law - 3rd floor new fountain	16 hr stag	1 - 250 mL					0.042	98.88	22.71	-0.009	6.386	13.87
			2 - 250 mL					0.097	109.2	7.951	0.003	6.538	13.65
			3 - 250 mL					0.083	95.53	8.551	0.03	6.236	13.09
			4 - 250 mL					0.054	84.45	3.906	0.072	5.189	11
			5 - 1000 m					0.062	63.34	2.985	0.059	5.629	10.2
			6 - 1000 m					0.051	44.77	2.615	0.021	6.51	10.23
B	Chemistry 3rd floor new fountain	16 hr stag	1 - 250 mL					0.06	53.66	13.59	-0.006	0.823	15.08
			2 - 250 mL					0.017	57.13	3.756	0.01	0.697	14.46
			3 - 250 mL					0.041	52.54	3.637	0.26	0.758	14.08
			4 - 250 mL					0.056	49.07	2.76	0.585	1.141	13.77
			5 - 1000 m					0.056	38.68	2.207	0.629	0.717	14.97
			6 - 1000 m					0.045	29.5	2.075	0.374	0.459	17.21

Table B.16: Difference between heated digestion and standard nitric acid preservation of samples

	Lead (ug/L)			Copper (ug/L)			Zinc (ug/L)			Tin (ug/L)			Iron (mg/L)		
Date	pH < 2.0	Heated	δ	pH < 2.0	Heated	δ	pH < 2.0	Heated	δ	pH < 2.0	Heated	δ	pH < 2.0	Heated	δ
Jul-07	0.695	1.086	0.391	258.2	272.6	14.4	90.17	76.72	-13.45	-0.069	-3.535	-3.466	21.91	42.56	20.65
	0.697	1.16	0.463	214.5	288.1	73.6	126.8	131.6	4.8	-0.266	-3.791	-3.525	22.89	48.75	25.86
	2.48	2.723	0.243	167.1	179.6	12.5	104.8	91.16	-13.64	-0.255	-4.195	-3.94	21.15	38.62	17.47
	0.962	1.302	0.34	91.39	105.7	14.31	137	80.96	-56.04	-0.305	-4.257	-3.952	43.31	60.12	16.81
	0.547	0.928	0.381	54.19	66.75	12.56	70.3	67.15	-3.15	-0.326	-4.087	-3.761	50.38	92.41	42.03
	0.532	1.234	0.702	50.56	61.79	11.23	116	96.94	-19.06	-0.356	-4.338	-3.982	51.43	77.32	25.89
Jul-07	72.22	68.76	-3.46	2583	2554	-29	330.9	280.8	-50.1	1.301	-3.089	-4.39	199.5	230.7	31.2
	84.43	79.66	-4.77	2642	2916	274	268.9	226.6	-42.3	1.146	-1.925	-3.071	236.2	278.8	42.6
	63.49	64.58	1.09	2436	2480	44	244.5	214.5	-30	1.028	-2.089	-3.117	180.1	228.4	48.3
	46.25	49.86	3.61	2199	2181	-18	409.4	262.7	-146.7	0.264	-3.007	-3.271	141.1	203.3	62.2
	75.43	77.96	2.53	4202	4169	-33	250.4	235.2	-15.2	1.329	-0.815	-2.144	319.3	397.7	78.4
	79.05	81.03	1.98	4363	4462	99	229.9	209.2	-20.7	1.984	-0.818	-2.802	344.3	432.4	88.1
Jul-14	12.26	14.77	2.51	211.1	233.7	22.6	267.1	272.9	5.8	0.46	-3.469	-3.929	42.58	64.79	22.21
	11.11	13.44	2.33	236.3	230.5	-5.8	166.5	127.2	-39.3	0.45	-3.916	-4.366	31.07	47.18	16.11
	8.401	8.667	0.266	261.4	259.2	-2.2	198.9	170.4	-28.5	0.309	-4.2	-4.509	32.86	53	20.14
	5.903	7.063	1.16	264.2	280.3	16.1	156.3	135.7	-20.6	0.326	-4.136	-4.462	24.74	46.27	21.53
	3.84	4.366	0.526	218	221.8	3.8	200.4	166.3	-34.1	0.39	-4.451	-4.841	117.6	149.4	31.8
	2.532	3.272	0.74	167.4	171.6	4.2	218.6	217.8	-0.8	0.277	-4.574	-4.851	225.3	306.8	81.5
Jul-28	17.88	22.37	4.49	1554	1618	64	1062	900	-162	79.14	98.83	19.69	25.28	45.08	19.8
	15.45	15.34	-0.11	1258	1107	-151	863.9	647.9	-216	48.61	59.51	10.9	15.54	33.2	17.66
	12.37	15.02	2.65	1184	1156	-28	805.7	705.8	-99.9	26.28	39.99	13.71	12.16	34.91	22.75
	12.03	13.25	1.22	1112	970.3	-141.7	1358	687.2	-670.8	22.16	38.96	16.8	90.93	55.58	-35.35
	11.47	12.62	1.15	1120	992.4	-127.6	727.2	552	-175.2	21.66	30.42	8.76	10.48	25.67	15.19
	12.18	13.34	1.16	1133	1016	-117	721.5	543.8	-177.7	25.16	37.92	12.76	13.27	31.46	18.19
Jul-28	7.599	9.698	2.099	174.4	192.9	18.5	160.8	108.9	-51.9	-5.831	1.479	7.31	9.372	26.04	16.668
	6.057	7.481	1.424	185.8	198.7	12.9	89.98	78.55	-11.43	-6.346	1.178	7.524	0.345	17.08	16.735
	4.664	5.732	1.068	168.9	175.1	6.2	98.58	85.82	-12.76	-6.236	1.194	7.43	2.522	16.86	14.338
	4.165	4.211	0.046	150.6	148.4	-2.2	391.2	111.3	-279.9	-6.397	1.108	7.505	5.954	17.7	11.746
	2.383	2.791	0.408	121.8	111.1	-10.7	83.95	63.27	-20.68	-6.23	1.22	7.45	2.21	24.61	22.4
	1.766	2.292	0.526	96.32	100.9	4.58	83.18	72.19	-10.99	-6.331	1.262	7.593	2.001	17.38	15.379
Jul-28	180.3	205.2	24.9	6759	7055	296	465	369.3	-95.7	-4.733	5.326	10.059	401.7	529.5	127.8
	8.811	11.81	2.999	651	721.7	70.7	208.7	566.2	357.5	-6.569	1.425	7.994	25.33	81.21	55.88
	3.815	4.754	0.939	345	347.3	2.3	113.6	94.57	-19.03	-6.612	1.124	7.736	12.91	32.18	19.27
	2.786	3.079	0.293	258	250.9	-7.1	153.8	110.8	-43	-6.669	0.929	7.598	14.25	30.47	16.22
	2.578	2.325	-0.253	175.6	169.8	-5.8	142.7	103.3	-39.4	-6.702	0.928	7.63	15.71	31.6	15.89
	1.005	1.318	0.313	87.49	84.15	-3.34	198.6	87.29	-111.31	-6.635	0.948	7.583	16.33	32.05	15.72
Aug-04	12.95	13.76	0.81	194.6	201.5	6.9	176.3	150.1	-26.2	0.452	1.763	1.311	23.63	43.69	20.06
	10.78	10.61	-0.17	255.3	245.6	-9.7	141.3	112.2	-29.1	0.24	0.975	0.735	19.68	34.52	14.84
	7.296	8.792	1.496	258.9	266.4	7.5	139.4	120.3	-19.1	0.388	1.154	0.766	18.01	39.41	21.4
	5.874	6.664	0.79	258.4	269.5	11.1	134.7	112.6	-22.1	0.324	1.132	0.808	20.18	42.64	22.46
	4.175	4.009	-0.166	201.8	180.5	-21.3	109.5	79.33	-30.17	0.346	1.031	0.685	28.94	44.75	15.81
	2.25	2.96	0.71	143.9	157.7	13.8	82.2	74.91	-7.29	0.324	1.123	0.799	39.58	65.96	26.38
	0.869	1.342	0.473	82.99	94.65	11.66	65.4	62.78	-2.62	0.448	1.045	0.597	19.03	40.68	21.65
Aug-04	1.439	1.716	0.277	93.14	89.56	-3.58	102.6	82.45	-20.15	0.136	0.914	0.778	20.1	37.88	17.78
	3.578	4.772	1.194	119.2	145	25.8	76.96	76.65	-0.31	1.047	1.975	0.928	18.19	40.72	22.53
	2.017	2.358	0.341	146.1	145.7	-0.4	81.99	67.26	-14.73	0.295	1.063	0.768	16.17	31.72	15.55
	1.489	2.15	0.661	143.3	148	4.7	78.33	65.64	-12.69	0.19	1.68	1.49	13.64	33.45	19.81
	1.056	1.507	0.451	131.9	140.8	8.9	74.32	65.82	-8.5	0.159	1.192	1.033	13.82	31.51	17.69
	1.604	1.773	0.169	76.98	71.14	-5.84	64.11	49.79	-14.32	0.363	1.623	1.26	34.13	42.63	8.5
Aug-04	5.925	6.817	0.892	140.1	150.3	10.2	153.1	132.6	-20.5	0.246	1.129	0.883	22.79	44.14	21.35
	4.708	5.616	0.908	168.9	179.9	11	106.6	91.73	-14.87	0.212	1.2	0.988	21.46	39.56	18.1
	3.971	3.744	-0.227	202.2	178.1	-24.1	106.6	76.89	-29.71	0.449	1.073	0.624	25.04	34.98	9.94
	2.691	3.473	0.782	198	218.5	20.5	98.15	86.27	-11.88	0.208	1.256	1.048	23.48	42.51	19.03
	1.673	1.918	0.245	164.2	24.92	-139.28	83.86	9.608	-74.252	0.197	0.979	0.782	21.67	52.56	30.89
	3.877	4.564	0.687	91.44	96.92	5.48	59.05	61.69	2.64	0.432	1.269	0.837	57.46	97.16	39.7

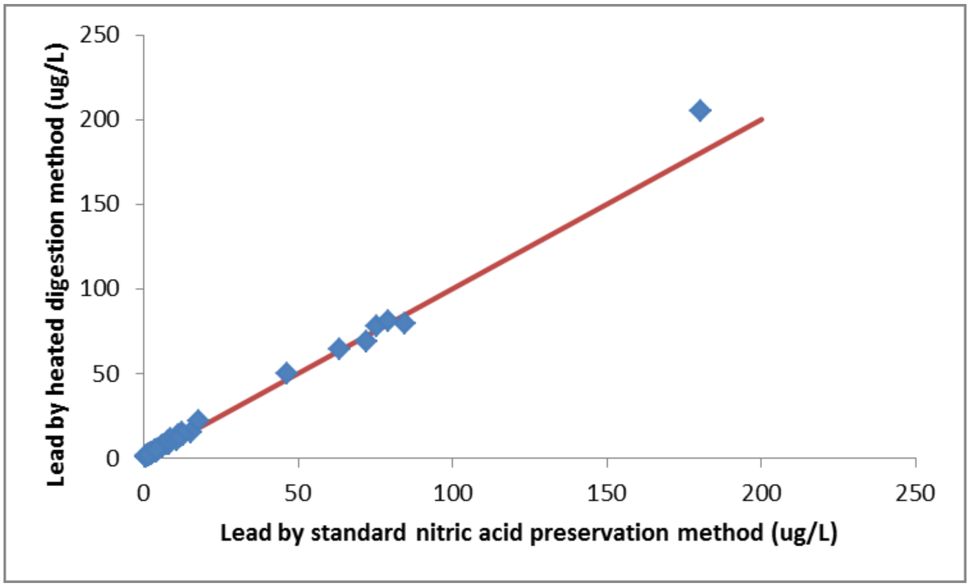

Figure B.1: Comparison of lead concentrations from samples by standard nitric acid preservation and by heated digestion

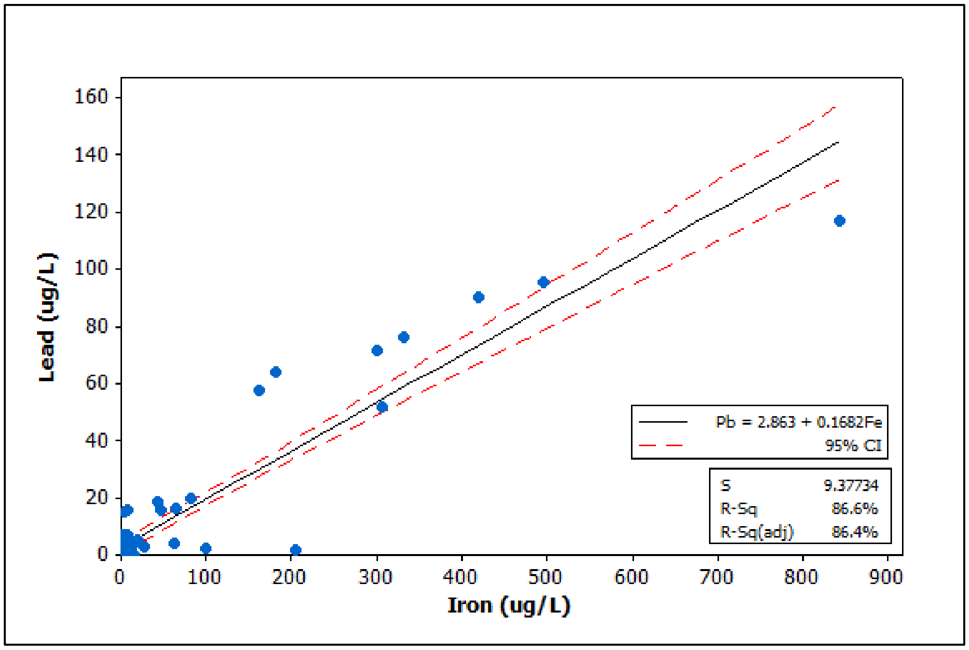

Figure B.2: Particulate lead as a function of particulate iron in the fountain investigation

Appendix C – Effects of Plumbing Flux on Metals Release

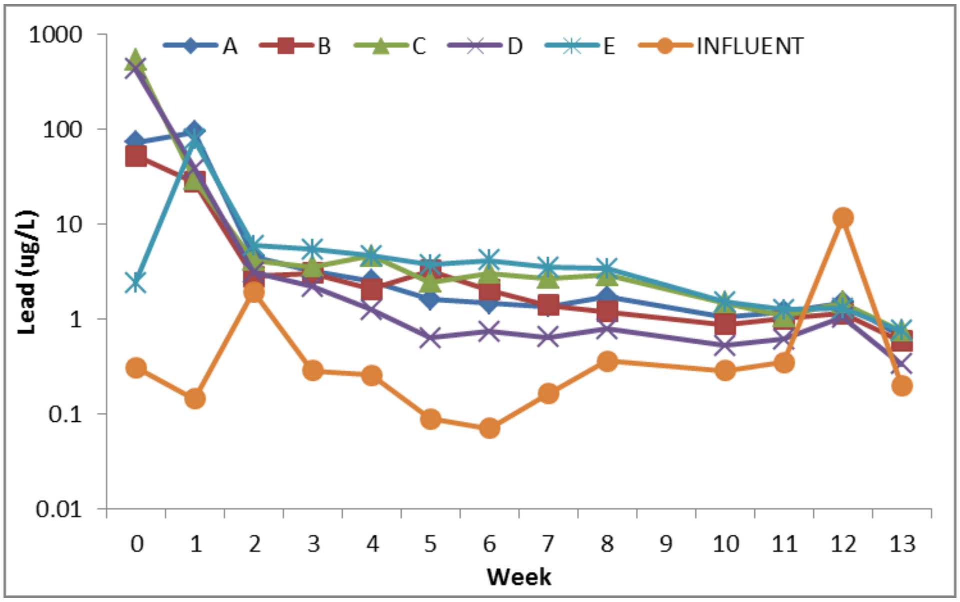

Figure C.1: Lead concentrations under low flow conditions

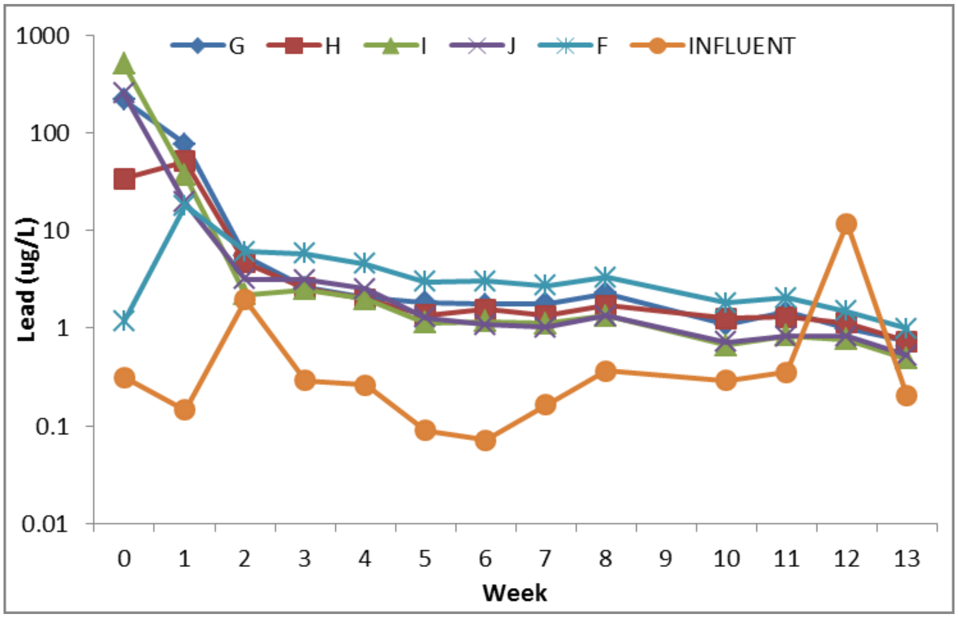

Figure C.2: Lead concentrations under high flow conditions

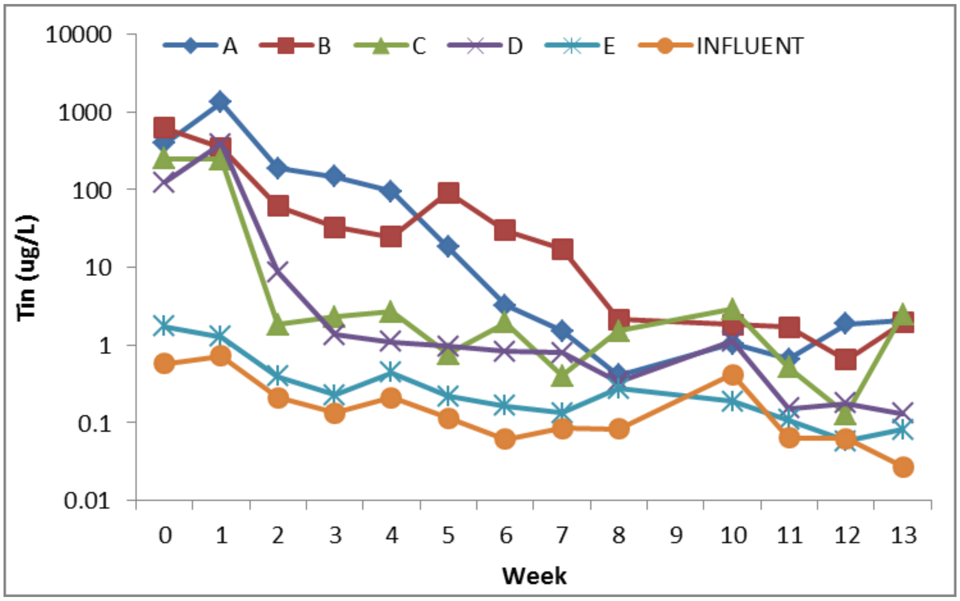

Figure C.3: Tin concentrations under low flow conditions

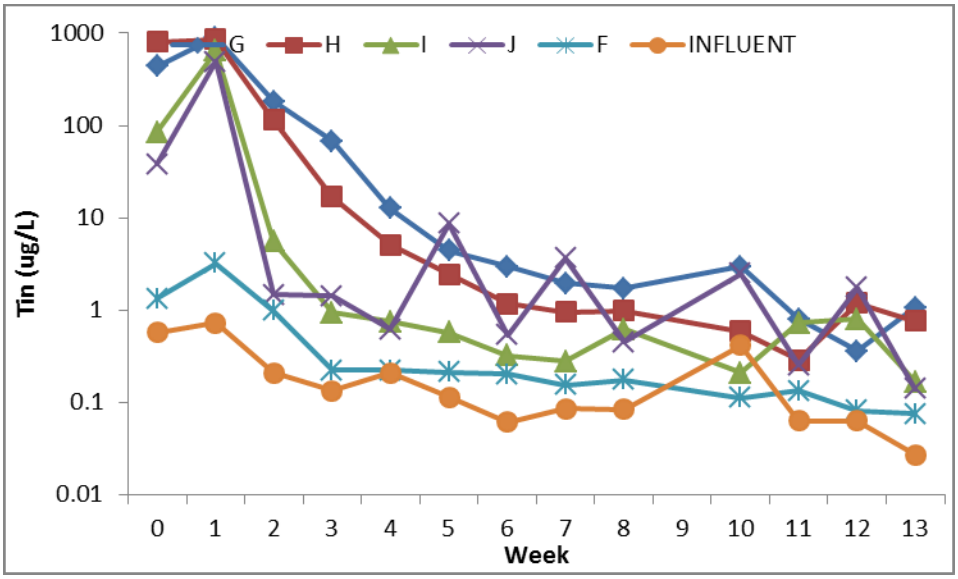

Figure C.4: Tin concentrations under high flow conditions

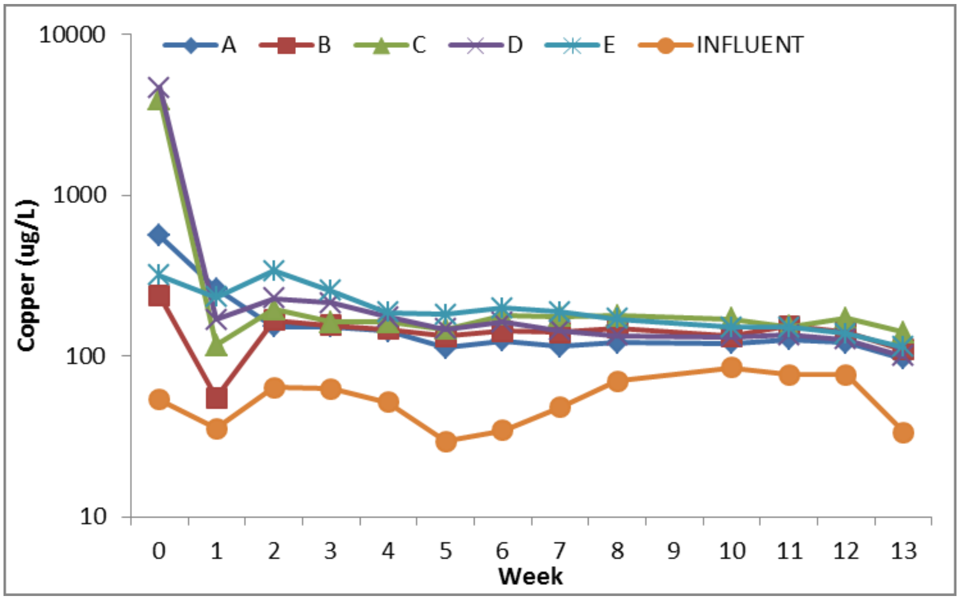

Figure C.5: Copper concentrations under low flow conditions

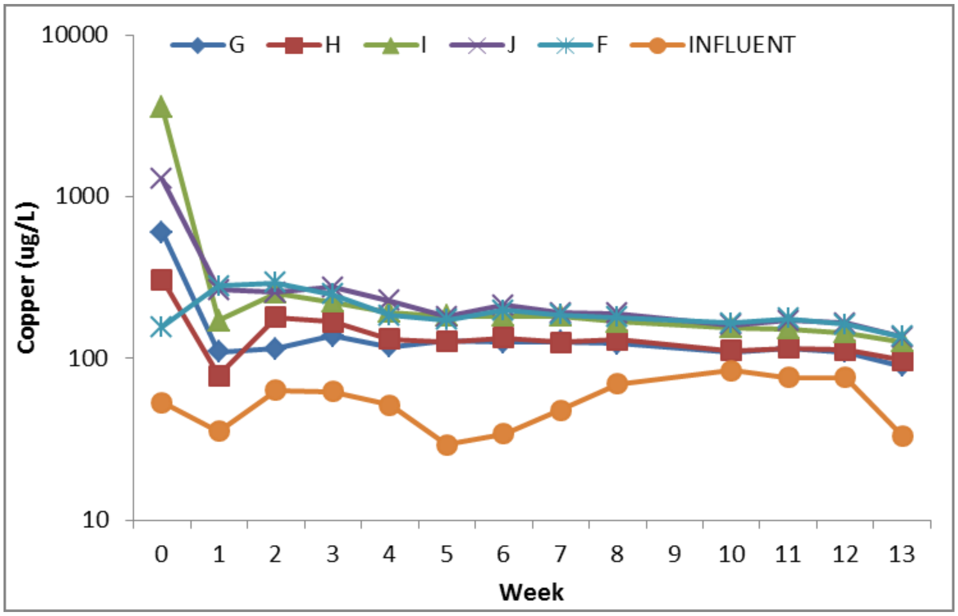

Figure C.6: Copper concentrations under high flow conditions

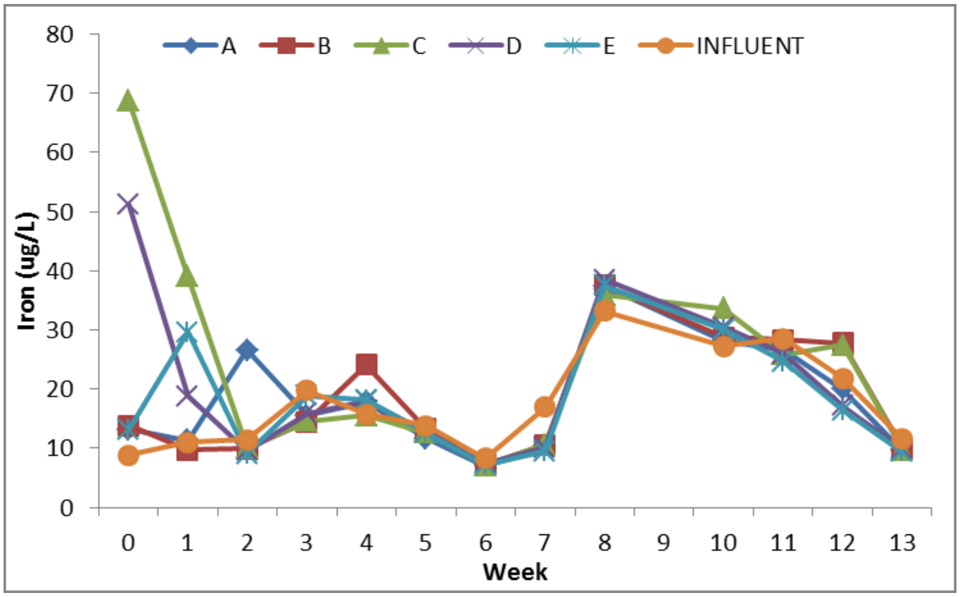

Figure C.7: Iron concentrations under low flow conditions

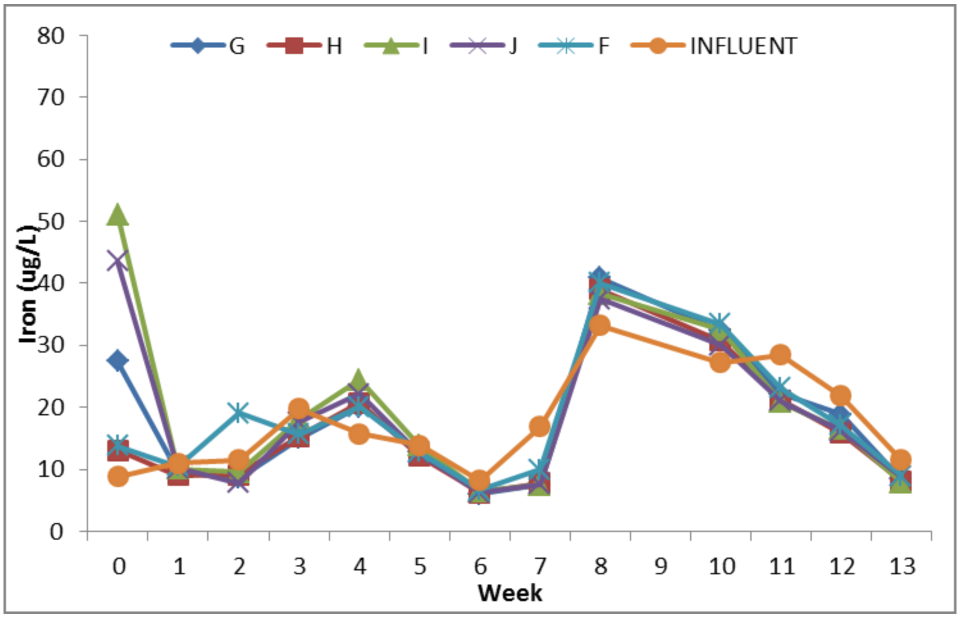

Figure C.8: Iron concentrations under high flow conditions

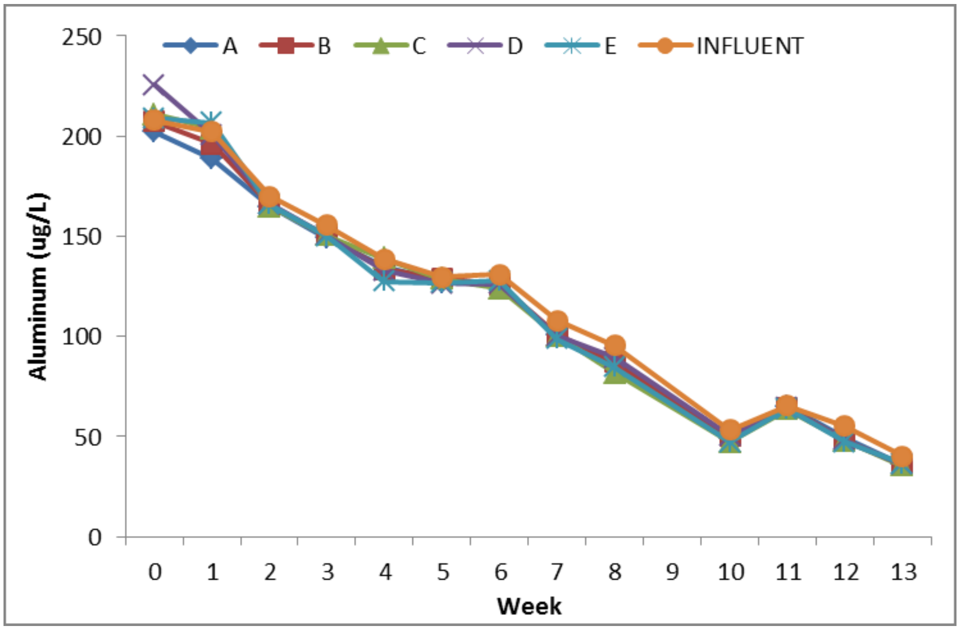

Figure C.9: Aluminum concentrations under low flow conditions

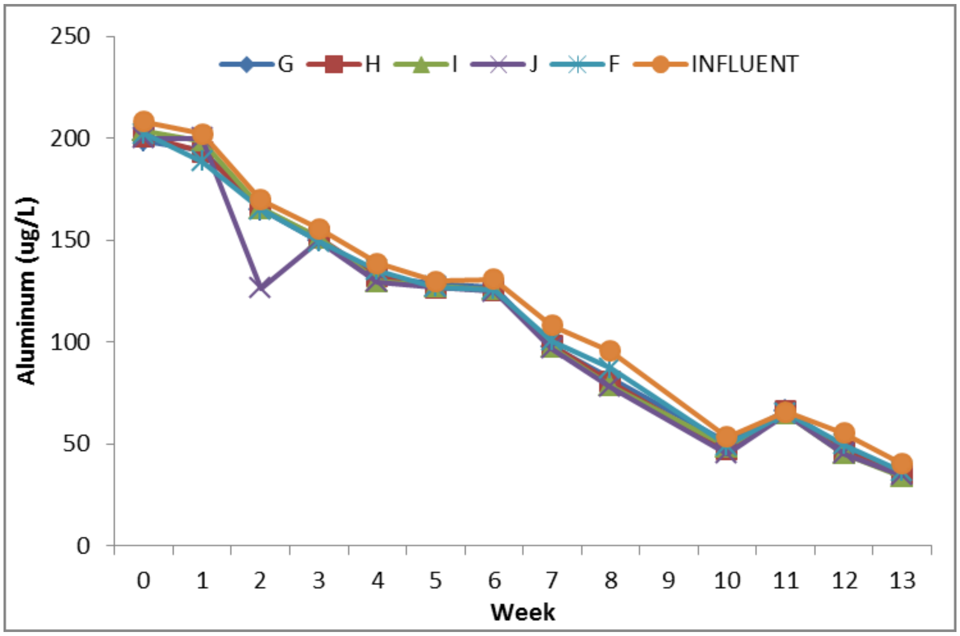

Figure C.10: Aluminum concentrations under high flow conditions

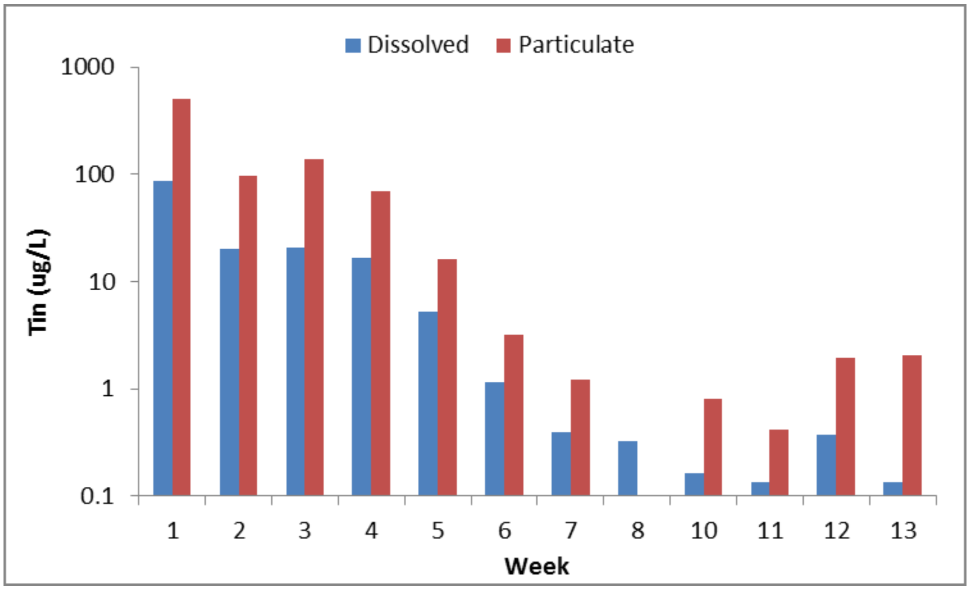

Figure C.11: Dissolved and particulate tin levels throughout flux experiment of segment A

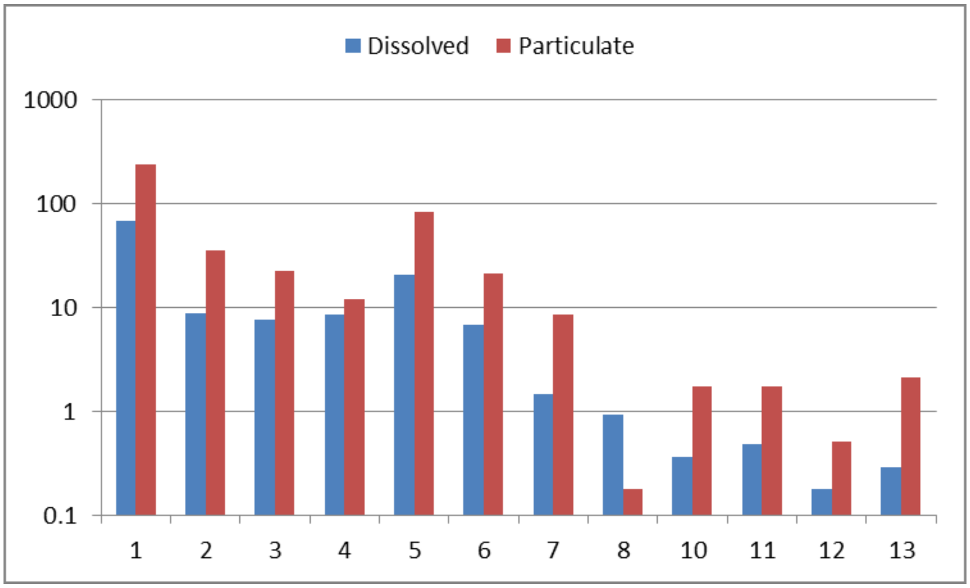

Figure C.12: Dissolved and particulate tin levels throughout flux experiment of segment B

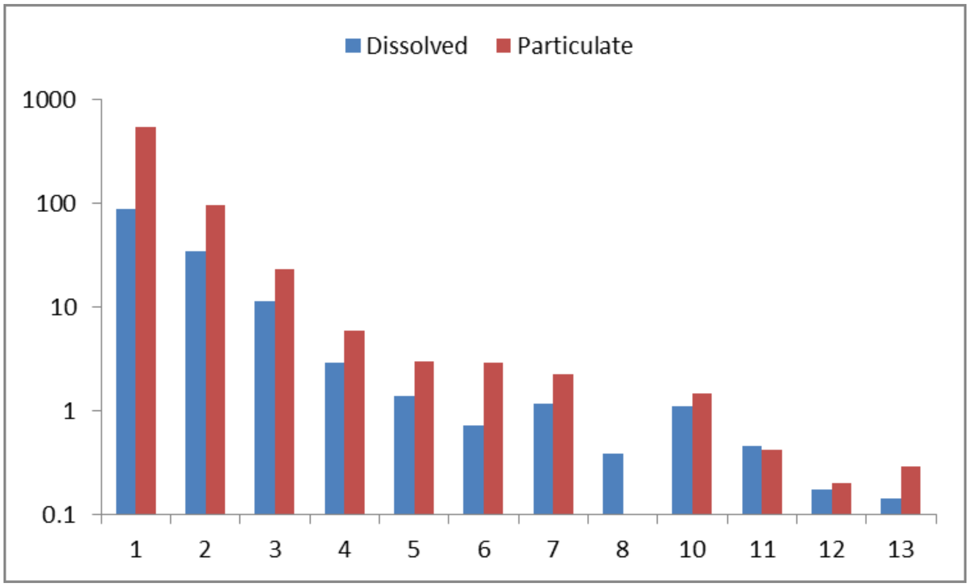

Figure C.13: Dissolved and particulate tin levels throughout flux experiment of segment G

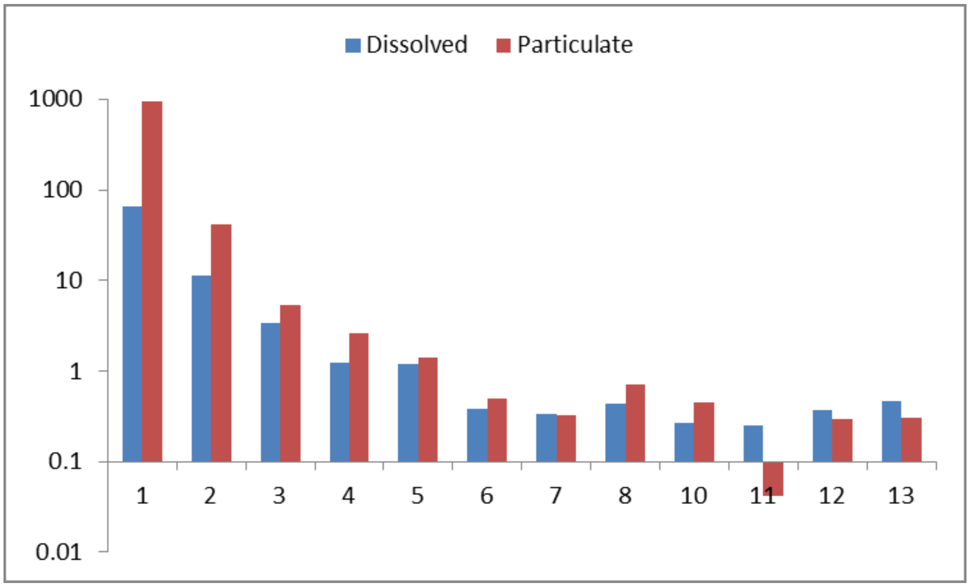

Figure C.14: Dissolved and particulate tin levels throughout flux experiment of segment H

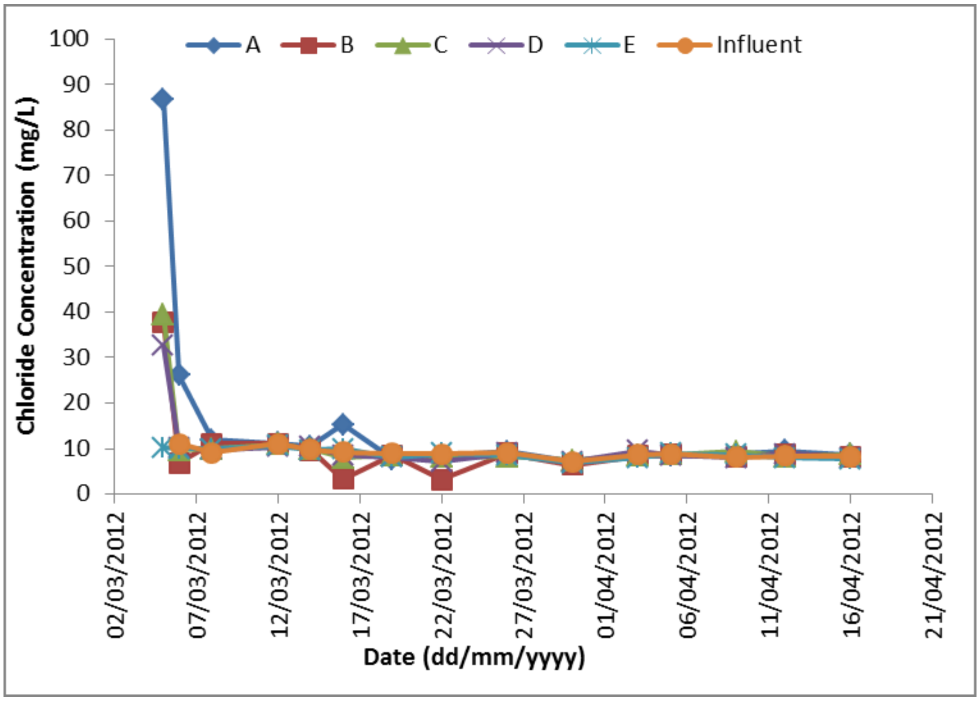

Figure C.15: Chloride concentrations from segments under low flow condition

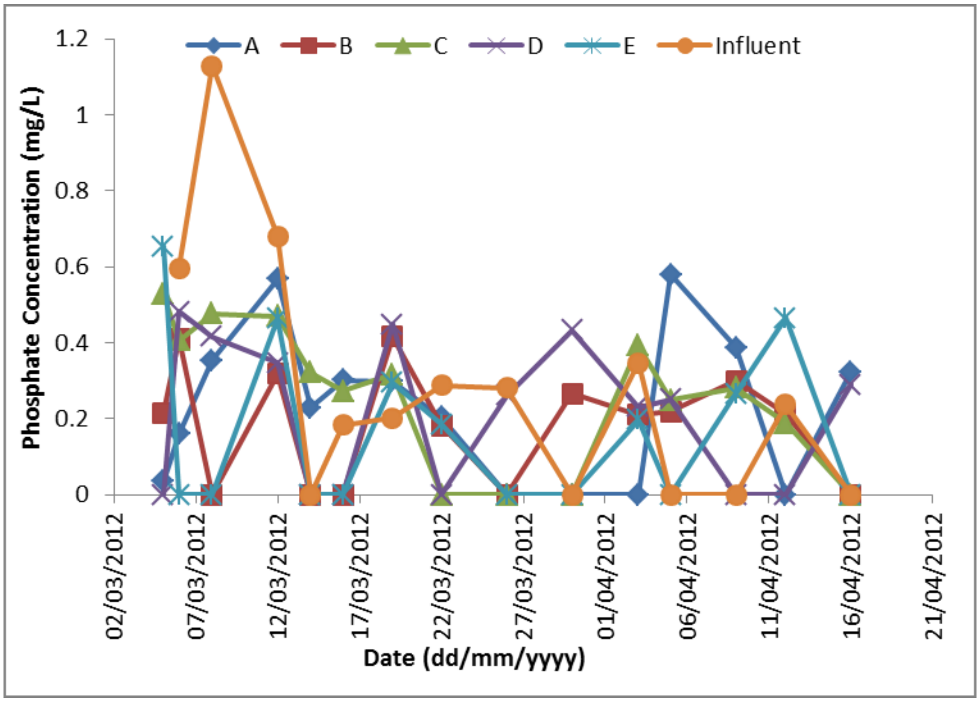

Figure C.16: Phosphate concentrations from segments under low flow condition

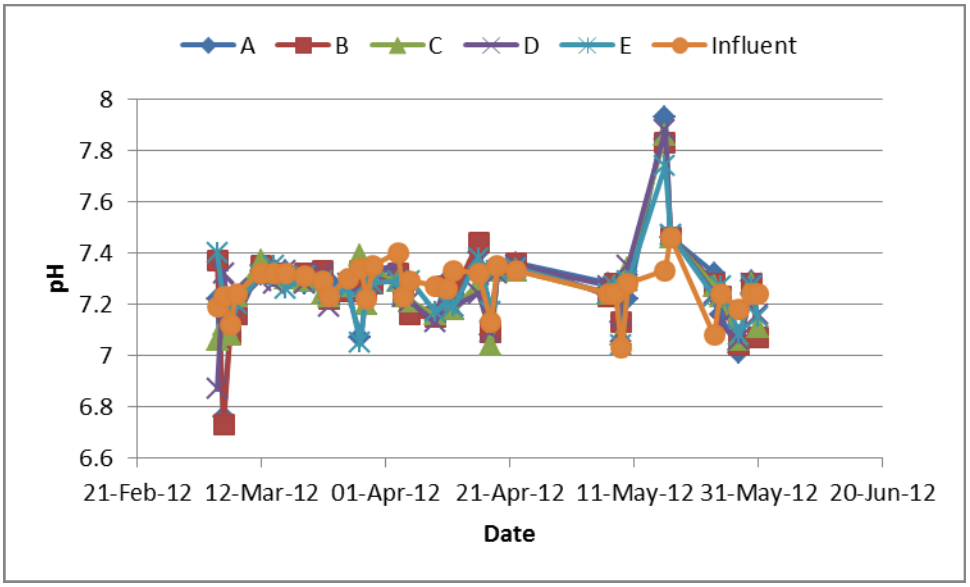

Figure C.17: pH of samples collected under the low flow condition

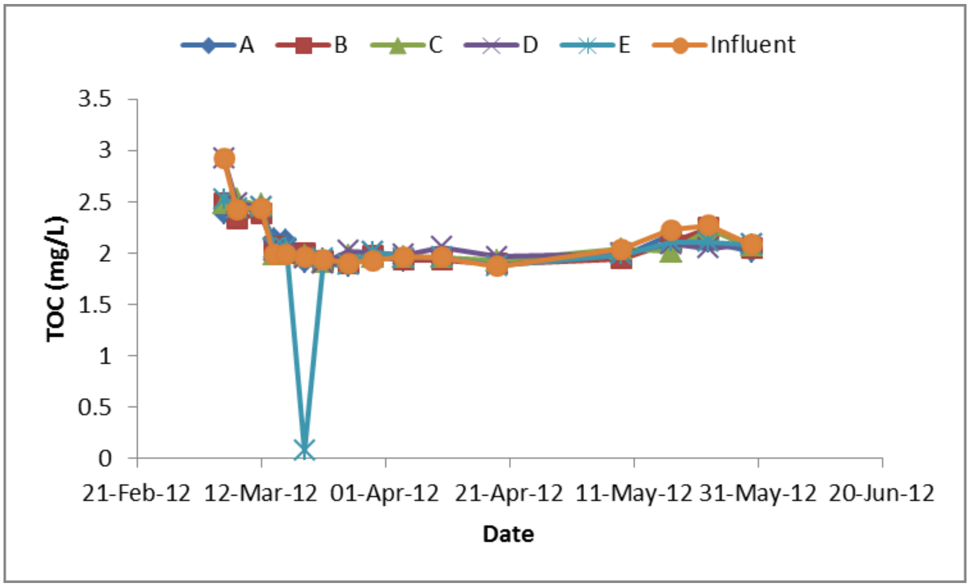

Figure C.18: TOC concentrations of samples collected under the low flow condition

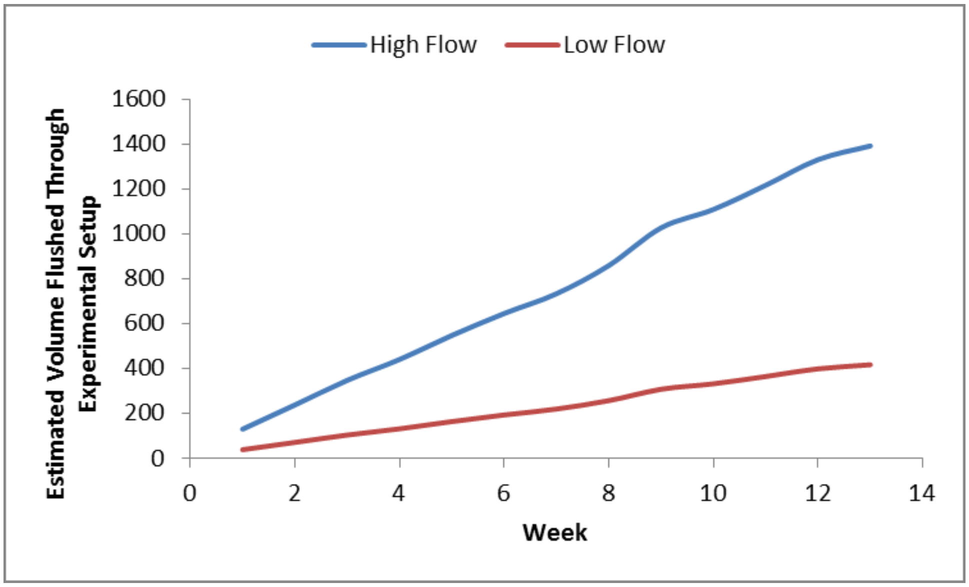

Figure C.19: Estimated volume flushed through experimental setup under low and high flow conditions