OPTIMIZING THE REMOVAL OF NATURAL ORGANIC MATTER IN DRINKING WATER WHILE AVOIDING UNINTENDED CONSEQUENCES FOLLOWING COAGULATION

by

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DEDICATION

I dedicate this thesis to my husband, Andy, for his continued patience, support, understanding and love along this journey.

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ABSTRACT

Over the past decade, the objectives for coagulation based drinking water treatment processes have changed significantly. These changes are a result of stringent goals related to natural organic matter (NOM) removal to mitigate the formation of subsequent harmful and health-related disinfection by-products (DBPs) and the need to achieve adequate filtration performance to ensure sufficient particle removal for pathogen control. Another concern associated with coagulation optimization is the potential unintended consequences of a coagulant change on the distribution system, specifically related to lead release from lead pipe and solder materials. Optimizing these multi-objectives in a direct filtration treatment process presents significant challenges for source waters characterized by low levels of turbidity, alkalinity and organic matter content.

Bench and pilot-scale experiments were conducted to evaluate the performance of ferric sulfate, polyaluminum chloride (PACl) and aluminum chlorohydrate (ACH) against aluminum sulfate (alum) using variable coagulation dosage and pH conditions for a direct filtration facility. Bench-scale experiments were conducted to optimize NOM removal during coagulation using traditional organic matter surrogates coupled with molecular size characterization techniques. Pilot-scale studies provided a snapshot of feasibility in terms of filtration performance for favourable bench-scale conditions and also identified optimal conditions for filtration performance. Results from pilot testing demonstrated that favourable conditions identified for increased potential NOM removals during bench-scale testing were significantly different than optimal filtration conditions identified during pilot studies; and, in fact, severely compromised direct filtration performance due to increased solids loading to the filters.

Bench-scale experiments evaluated lead leaching from lead and lead:tin solder galvanically connected to copper under stagnant conditions using variable chloride-to-sulfate mass ratio (CSMR) conditions for alum, ferric sulfate and PACl. Although recent research identifies high CSMRs (>0.5) as the main mechanism of attack in distribution systems following coagulant changeovers, CSMR was not the primary catalyst for lead leaching following the coagulant changeover conditions evaluated in this study. Residual concentrations of iron and aluminum remaining following coagulation were the principal contributors. Positive correlations were revealed between particulate iron and particulate lead concentrations following stagnation demonstrating that the adsorption of lead to iron oxides is a viable hypothesis for lead release.

LIST OF ABBREVIATIONS AND SYMBOLS USED

Al	aluminum
Alum	aluminum sulfate
ACH	aluminum chlorohydrate
BCAA	bromochloroacetic acid
BCDM	bromodichloromethane
BDCAA	bromodichloroacetic acid
^{o}C	degrees Celsius
$CaCO_3$	calcium carbonate
CDBAA	chlorodibromoacetic acid
CFD	Computational Fluid Dynamics
Cl^-	chloride
CO_2	Carbon dioxide
cm	centimeter
CSMR	chloride to sulfate mass ratio
Da	daltons
DBAA	dibromoacetic acid
DBCM	dibromochloromethane
DBP	disinfection by-product
DBPFP	disinfection by-product formation potential
DCAA	dichloroacetic acid
DO	dissolved oxygen

DOC	Dissolved organic carbon
ETSW	Extended Terminal Sub-fluidization Wash
Fil	filter
Floc3	post-flocculation
FRL	Filter Run Length
FRV	Filter Ripening Volume
FSP	Full scale plant
Fe	iron
ft	foot
h	hour
HAA	haloacetic acid
HAAFP	haloacetic acid formation potential
HBNS	high basicity non-sulfated
HPSEC	high pressure size exclusion chromatography
HW	Halifax Water
in	inch
JDKWSP	JD Kline Water Supply Plant
$KMnO_4$	Potassium Permanganate
L	liter
L/min	liters per minute
m	meter
m^2	square meter
m^3/m^2	square meters/ cubic meters

μm	micrometer
MBAA	monobromoacetic acid
MBNS	medium basicity non-sulfated
MCAA	monochloroacetic acid
μg/L	micrograms per liter
mg/L	milligrams per liter
min	minute
mm	millimeter
μL	micro liter
ML/d	million liters per day
mL/min	milliliters per minute
ML/m^2	million liters of water per square meter
mV	millivolt
MW	molecular weight
NOM	natural organic matter
NTU	nephelometric turbidity units
ORP	oxidation reduction potential
PACl	Polyaluminum chloride
PI	performance indicator
PM3	post-coagulation
PP1	Pilot plant train 1
PP2	Pilot plant train 2
QC	quality control

R^2	coefficient of determination
RO	reverse osmosis
RW	raw water
SEC	size exclusion chromatography
SO_4^{2-}	sulfate
SUVA	specific UV_{254} absorbance
TBAA	tribromoacetic acid
TCAA	trichloroacetic acid
THM	trihalomethane
THMFP	trihalomethane formation potential
TOC	Total organic carbon
UFRV	Unit Filter Run Volume
UV_{254}	Ultra violet absorbance at 254nm
WQMP	Water Quality Master Plan

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CHAPTER 1 INTRODUCTION

Over the past decade, the objectives for coagulation based drinking water treatment processes have changed significantly as a result of stringent goals related to natural organic matter (NOM) removal to meet disinfection by-product (DBP) regulations and the need to achieve adequate filtration performance to ensure adequate particle removal for pathogen control. Resulting from the reaction of organic matter and chlorine in subsequent disinfection processes, DBPs are regulated because certain species have been classified as carcinogenic, mutagens and toxicants and pose a significant health risk to humans when ingested through drinking water over an extended period of time (Health Canada, 2006). Balancing the optimization of these multi-objective goals in a direct filtration treatment process presents significant challenges in source waters characterized by low turbidity, low alkalinity and low organic matter content.

The optimization of both organic matter and particle removal for a direct filtration plant with low-level turbidity in the source water is challenging because of its limited treatment barriers. Direct filtration facilities are typically used to treat low turbidity (<10-NTU) source waters and coagulation processes within these facilities were historically optimized primarily with turbidity removal objectives in mind. Since a clarification stage does not exist between the coagulation and filtration stage, direct filtration requires effective charge neutralization and very small "pin" floc to ensure acceptable filtration performance is achieved in terms of filter headloss, particle removal and filter run times (Pernitsky and Edzwald, 2006).

Optimal conditions for turbidity removal are not always the same as those for NOM removal; in fact, the coagulant demand is usually governed by the concentration of NOM for low turbidity waters (Gregor et al., 1997 and Pernitsky and Edzwald, 2006). The coagulation pH and dosage required for organic matter removal does not only depend on the concentration of organic matter in the source water; recent researchers have reported that specific physical and chemical properties of NOM impact the removal of NOM during coagulation and the DBP formation potential of the treated water (Croue et al., 2000; Pernitsky and Edzwald, 2006; Ates et al., 2007). The negtive charge of NOM in surface waters is generally greater than that of particulate matter and, in turn, is associated with much higher coagulant demands for effective removal (Pernitsky and Edzwald, 2006).

In a direct filtration treatment plant, optimizing coagulation processes based solely on the removal of organic matter may cause significant problems with filtration performance and overall particle removals. Dosing to meet NOM removal goals in these facilities leads to high solids loading to the filters and results in early breakthrough, increased head loss rates and, therefore, shorter filter run times (Eikebrokk et al., 2007). In a direct filtration process, coagulation optimization is the primary means of ensuring optimal filtration performance is achieved and the stringent filtration goals of today's regulatory regime are achieved. In addition, the removal of soluble NOM from low-level turbidity source water presents another practical challenge related to the low concentrations of stable particles available to form acceptable floc (Gregor et al., 1997; Eikebrokk et al., 2007). In direct filtration facilities, coagulation processes must be optimized with multiple performance objectives in mind. There are noticeable gaps in literature pertaining to coagulation optimization of source waters characterized by low levels of turbidity, alkalinity, and organic matter, which is a problem inherent throughout Nova Scotia, and several other provinces across Canada.

Another potential concern associated with coagulation optimization is the potential unintended consequences of a coagulant change on the distribution system, specifically related to lead release from lead pipe and solder materials. Previous studies have reported that coagulant changeovers were a key factor in unexpected high lead concentrations in distribution systems (Dodrill and Edwards, 1995; Edwards et al., 1999). Evidence obtained through lead release data resulting from practical case studies and laboratory-based studies have demonstrated that a high chloride (Cl^-) to sulfate (SO_4^{2+}) mass ratio (CSMR) induces high galvanic currents and governs lead leaching incidences in distribution systems following coagulant changeovers (Dodrill and Edwards, 1995; Edwards et al., 1999; Dudi, 2004; Edwards and Triantafyllidou, 2007, Nguyen et al., 2010a; Nguyen et al., 2010c). Additionally, due to the limited database of lead release occurrences from these utilities, supporting data relating CSMR and lead leaching in systems with water sources characterized by low alkalinity and turbidity is limited and more research is required to validate this theory (EPA and AwwaRF, 2007).

1.1. RESEARCH QUESTIONS AND OBJECTIVES

The main objective of this thesis was to optimize the removal of organic matter DBP precursors in a direct filtration facility treating surface water with low levels of turbidity, alkalinity and organic matter while ensuring filtration performance is not compromised and significant or harmful effects with respect to lead leaching in the distribution system are not triggered. Bench-scale and pilot-scale experiments were designed to satisfy the following research sub-objectives:

Objective 1. Determine favourable coagulation conditions for the removal of organic matter from a low turbidity, low alkalinity, and low organic matter source water through bench-scale alternate coagulant studies using ferric sulfate, polyaluminum chloride (PACl), aluminum chlorohydrate (ACH) and alumunim sulfate (alum) at variable coagulant dosage and pH conditions.

Objective 2. Evaluate particle removal and filtration performance using a direct filtration pilot plant for the favourable coagulation conditions determined for NOM removal using ferric sulfate, PACl, ACH and alum. If these conditions are significantly different from the conditions identified in Objective 1, determine if balanced conditions to meet performance goals can be achieved.

Objective 3. Evaluate potential "unintended consequences" of chemical changeovers on finished water quality and distribution systems related to lead release.

Objective 4. Develop a framework for implementing and evaluating coagulation optimization studies to be used by other utilities.

1.2. ORGANIZATION OF THESIS

The main chapters in this thesis were organized and formatted with the intention of being submitted for publication; therefore, each contains an abstract, introduction, materials and methods, results and discussion, and conclusions section. Raw and supplemental data for Chapters 4 through 7 are provided in Appendices A through D, respectively.

Chapter 2 outlines the rationale behind this research project and presents general background information on NOM occurrence, coagulation mechanisms, coagulation optimization with alternate coagulants and lead release consequences associated with galvanic corrosion and coagulant changeovers.

Chapter 3 describes raw water sampling and collection, equipment and analytical procedures that are common to the experimental designs presented in **Chapters 4, 5, 6 and 7**. For clarity, materials and methods that are chapter specific are described within that particular chapter.

Chapter 4 presents findings from the experimental and statistical validation procedures used to verify that the pilot treatment process, used for coagulation optimization trials in **Chapter 5,** replicates the corresponding full-scale direction filtration plant and that the two pilot treatment trains produced equivalent water quality.

Chapter 5 presents results of the bench-scale and pilot-scale experiments conducted to optimize organic matter and particle removal for a direct filtration plant through evaluating the performance of ferric sulfate, polyaluminum chloride (PACl) and aluminum chlorohydrate (ACH) against aluminum sulfate (alum) using variable coagulant dosage and pH conditions.

Chapters 6 and **7** report on the results of experiments designed to evaluate the role of a coagulant change in causing lead leaching in lead-to-copper galvanic connections. The coagulants studied include alum, PACl and ferric sulfate and the two lead bearing plumbing materials studied were lead:tin solder and passivated lead pipe, both in connection with copper pipe. This work contributes to the established data set for coagulant changeover studies with a particular emphasis on very low alkalinity water (less than 10 mg/L as $CaCO_3$) and high CSMR values.

Finally, **Chapter 8** provides a summary and conclusions of all individual research projects presented in this thesis and **Chapter 9** offers recommendations and opportunities for future research projects that were beyond the scope of this thesis, but merit additional investigation.

CHAPTER 2 BACKGROUND

2.1. PROJECT RATIONALE

This research project was carried out as part of a much larger 5-year collaborative project between Halifax Water (HW) and Dalhousie University. HW is the municipal water, wastewater and stormwater utility serving the residents of the Halifax Regional Municipality in Nova Scotia, Canada. In 2005, HW completed its first formal Water Quality Master Plan (WQMP) document to be used as a roadmap to ensure safe, high quality water is delivered to consumers for the foreseeable future. Water quality master planning examines water quality regulations and trends, and makes reasonable estimations of what future regulations will be, and therefore allows the utility to set long term water quality goals. Master planning also affords the utility time to select the most cost effective response to future regulations and to plan for the required capital expenditures. Dalhousie University, HW and the NSERC collaborated to execute this water quality research program.

The focus of the WQMP has largely been on upgrades and investigations concerning the JD Kline Water Supply Plant (JDKWSP); HW's most mature treatment facility. This plan focused on addressing research needs at this facility to ensure that the JDKWSP will be able to maintain treatment performance in an increasingly volatile regulatory regime, despite the advancing age of this facility. Carefully planning for future demands and regulatory changes ensures the facility is maintained and upgraded in a sustainable manner.

The JDKWSP, commissioned in 1977, is HW's largest drinking water plant. The JDKWSP is a direct filtration surface water treatment plant with a capacity of 220 ML/day (currently supplies ~ 98ML/day) and is located on Pockwock Lake. In general, Pockwock Lake is characterized by low alkalinity (<1-mg/L as $CaCO_3$), pH (4.9 to 5.4) and turbidity (0.28 to 0.49), with low organic carbon concentrations (1.4 to 3.3 mg/L). These conditions pose several significant challenges when developing drinking water treatment solutions and optimizing current facilities to meet more stringent regulations. The optimization of coagulation processes, backwash procedures, mixing conditions, and disinfection practices were all key issues that HW targeted for this facility.

To aid in addressing these research needs, a direct filtration pilot-scale treatment plant was commissioned in 2007 at the JDKWSP to be used as an investigative tool in the implementation of this research plan. Since many of the research tasks were directly related to process improvements, in order to be fully evaluated, they must be executed at either pilot-scale or full-scale. Full-scale research entails unacceptable risks to public health, therefore the pilot plant would close the gap between bench-scale and full-scale research and provide a means of fully evaluating the proposed process modifications without posing a public health risk.

One of the key water quality objectives identified in the WQMP was the reduction of DBPs. Given that DBPs are of concern to water consumers and that they are a suspected carcinogen, HW directed efforts towards DBP reduction. Although, at the time, the trihalomethane (THM) levels measured in HW's distribution systems met current regulatory requirements (100-µg/L), there was much room for improved performance based on what others in the industry were achieving. There was also some concern about whether the plant could maintain compliance under more stringent regulations, specifically the 80-µg/L regulatory requirements currently in force in the United States. At the time, haloacetic acids (HAA_5) were not regulated in Canada, but were regulated to a maximum contaminant level of 60-µg/L in the United States. Therefore, HW set aggressive THM and HAA objectives in the WQMP of 80 µg/L and 60 µg/L, respectively, for this facility.

As a piece of this large research program, this thesis research was intended to optimize chemical coagulation processes for the removal of NOM to minimize DBPFP without compromising particle removals in a direct filtration water treatment system. As a secondary objective, HW was interested in investigating unintended consequences associated with coagulant changeovers on lead release in the distribution system. To that end, HW was a participating utility in Water Research Foundation Project #4088, investigating the potential effects of a coagulant changeover on lead release from lead plumbing components (Nguyen et al., 2010a).

There are noticeable gaps in literature pertaining to coagulation optimization of surface water characterized by low alkalinity and turbidity. In addition, there is a lack of research pertaining to the optimization of direct filtration treatment processes to meet increasingly stringent NOM and turbidity removal requirements. Additionally, due to the limited database of lead release occurrences resulting from coagulant changeovers, supporting data relating lead leaching and coagulant changeovers in systems with water sources characterized with low alkalinity and turbidity was limited (EPA and AwwaRF, 2007). Accordingly, the results of this research will be useful to both water utilities and regulatory applications within the water treatment industry.

2.2. COAGULATION OPTIMIZAITON

NOM in Drinking Water. All drinking water supplies contain organic matter. NOM refers to the organic complexes in water bodies that result from natural sources through the chemical and microbial breakdown of vegetation and soil-based materials (MWH, 2005). Typically, NOM exists in surface water at concentrations ranging from 1 to 20 mg/L, but the quality and quantity is source specific (MWH, 2005). The presence of NOM, no matter what the concentration, impacts several water quality parameters and processes in water treatment. NOM is a major cause of aesthetic quality problems such as yellow colouring, taste and odour (MWH, 2005). NOM in drinking water has no apparent harmful effect to humans, however, in combination with chlorine, NOM can result in the formation of DBPs such as THMs and HAAs. Many of these DBPs are carcinogenic when ingested through drinking water over an extended period of time (Health Canada, 2006; Health Canada, 2008). Due to aggressive THM and HAA regulations, water treatment facilities have been faced with developing new strategies to achieve increased organic matter removal to mitigate the formation of such DBPs.

The optimization of coagulation processes for the removal of NOM is not a new idea in the water industry. For drinking water research, NOM has traditionally been optimized through the evaluation of NOM surrogate parameters such as total organic carbon (TOC), dissolved organic carbon (DOC), ultra-violet light absrobance at 254 nm (UV_{254}) and specific UV_{254} absorbance (SUVA). More advanced NOM characterization techniques to determine optimal coagulation conditions is only recently gathering attention. A number of researchers have reported that specific physical and chemical properties of NOM, including the molecular weight of organic constituents, all impact the removal of NOM during coagulation (Croue et al., 2000; Liang and Singer, 2003; Ates et al., 2007). Therefore, characterizing the organic matter content in the both raw and treated water has become a useful tool for evaluating the efficiency of coagulation processes and for optimizing organic matter removal.

The specific physical and chemical properties of NOM can be established through the use of high-performance size exclusion chromatography (HPSEC) and resin fractionation techniques, respectively. NOM molecules are all unique but share similar characteristics. Fractionation selects a sub-group of these molecules from the mixture that share a narrower range of common properties than the entire aggregate (Croue et al., 2000). Resin fractionation is a technique using ion-exchange resins to absorb specific organic compounds out of solution and essentially separates the water samples into specific organic fractions, which include both hydrophobic and hydrophilic neutrals, bases and acids (Croue et al., 2000). HPSEC separates the NOM molecules based on molecular size, so that the molecular weight distribution can be determined. Large molecules move through the gel column faster than smaller ones. For this research, the column is interfaced with a UV_{254} detector and the molecular weight distribution is obtained by comparing the response of the NOM sample with that of standard molecules (usually proteins) of known molecular weight.

Organic matter is often described in terms of hydrophobic and hydrophilic fractions and there is conflicting literature regarding which NOM types are predominant as precursors of THMs and HAAs. The THM formation potential (THMFP) and HAA formation potential (HAAFP) is affected by the type and concentration of NOM and the chlorination pH, temperature, dosage and contact time (Liang and Singer, 2003). Recently, research efforts have attempted to correlate DBPFP with fundamental characteristics of organic matter (i.e., molecular weight, structure, aromaticity, etc.) and with NOM surrogate parameters such as DOC, UV_{254} and SUVA (Croue et al., 2000; Liang and Singer, 2003 and Ates et al., 2007). Several researchers have reported that the hydrophobic, aromatic NOM fractions and humic substances are the principal DBP precursors and, therefore DBPFP correlates with UV_{254} and SUVA levels in the raw water (Croue et al., 2000; Liang and Singer, 2003 and Ates et al., 2007). However, recent research highlights the contributions of the non-aromatic, hydrophilic organic fraction as being an important precursor to DBPFP and, therefore, these raw water UV_{254} and SUVA values exhibit weak correlations with DBPFP. (Ates et al., 2007).

Generally, research agrees that highly aromatic and high molecular weight (MW) organic compounds are associated with hydrophobic NOM and have been shown to be more amenable to removal by coagulation than hydrophilic NOM (Liang and Singer, 2003; Pernitsky and Edzwald, 2006). Hydrophilic organic matter typically encompass non-aromatic, low MW compounds with a significantly lower charge density than hydrophobic organic matters and are less amenable to removal by coagulation (Liang and Singer, 2003; Pernitsky and Edzwald, 2006).

Coagulation. In drinking water treatment, coagulation is a process in which a chemical coagulant is added to destabilize particles and remove dissolved organic matter through complexation reactions followed by a phase change (Pernitsky, 2003; Pernitsky and Edzwald, 2006). Coagulation processes are followed by a flocculation, or slow mixing, stage that promotes the aggregation of these destabilized particles and precipitation/adsorption of products into larger "floc" particles that are subsequently removed by clarification and/or filtration processes (MWH, 2005). The overall size and density of the floc formed is dependent on the subsequent processes used to remove the flocculated particles. Mixing is also a very important aspect of coagulation and flocculation processes; it is central to (1) the adequate dispersion of the chemical coagulant (rapid mixing during coagulation) and (2) the promotion of contact between particles and the rate of the destabilization and complexation reactions (slow mixing or flocculation) (MWH, 2005).

The four key mechanisms associated with the removal of dissolved NOM and particles during coagulation processes are enmeshment, adsorption, charge neutralization/destabilization and complexation/precipitation (Pernitsky, 2003). The mechanisms associated with the removal of NOM and particles are very different, therefore, the relative concentrations of these contaminants greatly affect the chemistry of coagulation. As described by Pernitsky and Edzwald (2006), when considering the removal of particles alone, the two primary coagulation mechanisms are (1) charge neutralization of the negatively charged particles by positively charged dissolved metal species and (2) enmeshment of colloids in precipitated metal hydroxide solids. The coagulation mechanisms involved in NOM removal are (1) complexation of NOM with the dissolved metal species that leads to precipitation of NOM-metal complexes, (2) the complexation of NOM with dissolved metal species that is subsequently adsorbed to precipitated metal hydroxide solids and (3) the direct adsorption of NOM onto precipitated metal hydroxide solids (Pernitsky and Edzwald, 2006).

There are many important factors affecting the coagulation of NOM and particles including the overall concentrations of both dissolved metal species and precipitated metal hydroxide solids, the raw water NOM and particle levels, the physical and chemical properties of NOM and particles (particularly the overall charge density of these contaminants) and the pH of coagulation (Pernitsky and Edzwald, 2006). With respect to process control, coagulation dosage and pH are the most important operational parameters for optimizing the overall removal of NOM and particles. However, optimal conditions for turbidity removal are rarely the same as those for NOM removal; in fact, the coagulant demand is usually governed by the concentration of NOM for low turbidity waters (Gregor et al., 1997; Pernitsky and Edzwald, 2006).

When coagulation occurs, NOM reacts and binds with metal ions and it has been shown by many researchers that the coagulant demand is normally controlled by NOM-metal interactions and not particle-metal interactions (Edzwald, 1993; MWH, 2005; Pernitsky and Edzwald 2006). The negative of NOM in surface waters is generally higher than that of particulate matter and, in turn, is associated with much higher coagulant demands for effective removal (Pernitsky and Edzwald, 2006). For example, Pernitsky and Edzwald (2006) report total negative charge densities for aquatic fulvic acid at 5 to15 μg/L. The higher the pH, the higher the negative charge due to ionization of carboxyl and phenolic functional groups. The magnitude of negative charge is specific to each organic fraction in the water (hydrophilic versus hydrophobic and the solute classes within each such as humic and fulvic acids). Whereas, for a clay suspension, the total negative charge density ranges from 0.05 to 0.5 μg/L, which are substantially lower than NOM. The higher the pH, the higher the negative charge due to ionization of the metal oxide or hydroxyl group on the surface of the particle (Pernitsky and Edzwald, 2006). In addition, NOM can adsorb on particles and control their particle stability, increasing the negative charge of the particle and requiring higher coagulant dosages to remove them from the water (Pernitsky and Edzwald, 2006). Therefore, the concentration and nature of NOM controls coagulant dosages and overall organic matter removals. This is the case for most raw water combinations, except for very low TOC water and high turbidity water.

Coagulation pH affects the charge density of the dissolved organic matter and particles and also affects the distribution of the metal species during coagulation. At the pH of minimum solubility, the maximum amount of coagulant is converted to solid phase-floc particles (Pernitsky, 2003). For low pH values, highly charged dissolved metal species are dominant and, as pH values increase, the charge of the dissolved metal species decreases. At pH values much higher than the pH of minimum solubility, negatively charged species begin to dominate. The aluminum hydroxide solid phase formed upon precipitation has a surface charge that is dependent on pH (Pernitsky, 2003). The overall distribution of the metal species are also dependent on temperature, as lower temperatures cause a shift of solubility diagrams to a higher pH range. However, the overall affect of temperature is dependent on the chemical coagulant used (Pernitsky and Edzwald, 2006).

The pH of coagulation and coagulant dosage required for the removal of NOM cannot be predicted because of several influencing factors such as particles, temperature, hardness and anions present, which will affect the speciation of NOM in the water. Nevertheless, some generalizations with respect to pH and dose have been made. As pH increases, humic species become more ionized as carboxyl groups lose protons and the charge of metal coagulants is reduced, therefore dictating higher coagulant dosages. In a higher pH range ($pH > 6.5$), the metal species present is predominantly in contact with precipitated hydroxide to form amorphous species (Pernitsky and Edzwald, 2006). However, in the low pH range ($pH < 5$), the metal species is predominantly in a dissolved metal form and the higher charge is more effective for complexation and charge neutralization (Pernitsky and Edzwald, 2006).

Direct Filtration. Direct filtration treatment plants do not include a clarification stage between coagulation and filtration processes. Direct filtration processes are typically used for raw water sources with very low turbidity values (<10-NTU) and low coagulant dosage requirements (Pernitsky and Edzwald, 2006). Due to the limited treatment barriers, direct filtration processes require optimal charge neutralization and optimally sized small "pin-point" floc to ensure acceptable solids loadings are applied to the filters to minimize filter headloss and maximize filter run volumes (Pernitsky and Edzwald, 2006). Dosing to meet NOM removal goals in these facilities leads to high solids loading to the filters and results in early breakthrough, increased head loss rates and, therefore, shorter filter run times (Eikebrokk et al., 2007).

In a direct filtration treatment plant, optimizing coagulation processes based solely on the removal of natural organic matter may cause significant problems with filtration performance and overall particle removals. In these plants, coagulation optimization is the primary means of ensuring optimal filtration performance is achieved and the stringent filtration goals of today's regulatory regime are achieved. In addition, the removal of soluble NOM from low-level turbidity source water presents another practical challenge related to the low concentrations of stable particles available to form acceptable floc (Gregor et al., 1997; Eikebrokk et al., 2007). In direct filtration facilities, coagulation processes must be optimized with multiple performance objectives in mind.

Coagulants Studied. There were four coagulants evaluated during the experiments conducted as part of this research project; alum, ferric sulfate, a medium basicity non-sulfated (MBNS) PACl and a high basicity non-sulfated (HBNS) ACH. These coagulants were chosen based on preliminary jar testing, coagulant supplier recommendations and recent studies supporting their use for treating similar source waters using direct filtration treatment processes.

Recent research has shown that high basicity PACls are well suited for water sources characterized by low turbidity, organic matter and alkalinity due to the highly charged polymeric species present and the low alkalinity consumption of the coagulant (Pernitsky and Edzwald, 2003; Pernitsky and Edzwald, 2006). Polyaluminum coagulants are produced by the partial neutralization of aluminum salts, which results in the creation of highly charged polymeric species as well as the monomeric species present during alum coagulation (Pernitsky and Edzwald, 2003; Pernitsky and Edzwald, 2006). Polyaluminum coagulants are available in a wide range of strengths and basicities, which refers to their degree of neutralization. The basicity of PACl coagulants that are commercially available ranges from 15 to 85%; with a low basicity corresponding to a 15-35% and a high basicity representing the 60-85% range (Pernitsky and Edzwald, 2003; Pernitsky and Edzwald, 2006). The basicity of the coagulant affects both the alkalinity consumption of the coagulant and the aluminum species present during coagulation. As the basicity increases, so does the fraction of polymeric species that is present, whereas, the alkalinity consumption decreases. Therefore, high basicity PACls have a higher fraction of polmeric species and are better suited for low alkalinity waters, whereas the opposite is true for low basicity PACl (Pernitsky and Edzwald, 2003; Pernitsky and Edzwald, 2006).

According to Pernitsky (2011), optimal coagulation performance for aluminum-based coagulants is typically seen at pH values close to the pH of minimum solubility where dissolved aluminum residuals are minimized and the presence of aluminum hydroxide precipitates for subsequent NOM adsorption is maximized. In contrast, ferric-based coagulants are more effective at very low pH values, where positively charged species are present and the overall negative charge of NOM is less (Pernitsky, 2010). Volk et al. (2000) reported that several researchers identified optimal precipitation pH ranges of 4-5 with ferric-based coagulants and at 5-6 with alum. For alum, low pH values (pH = 5.5) maximize organic matter removal, whereas these low pH conditions are not required for PACls (Pernitsky, 2010). Furthermore, Pernitsky and Edzwald (2006) noted optimal PACl and ACH performance at coagulation pH values between 6-7, with higher coagulation pHs being associated with higher basicity products.

2.3. EFFECTS OF COAGULANT CHANGEOVERS ON LEAD CORROSION

A particular concern associated with coagulation optimization is the potential unintended consequences of a coagulant change on the distribution system, specifically related to lead release from lead pipe and solder materials. Common coagulants are typically chloride and sulfate based (i.e.; alum, ferric chloride, PACl, ferric sulfate, etc). Therefore, coagulant based changes to a water treatment process can significantly alter the ratio of chloride and sulfate concentrations in the finished water. Following the introduction of new DBP regulations, many utilities were faced with coagulant changeovers, which inevitably resulted in unusual lead leaching issues in their distribution system, which were not easily corrected with the usual corrosion control measures (Dodrill and Edwards, 1995; Edwards et al., 1999). Evidence obtained through lead release data resulting from practical case studies and laboratory-based studies have demonstrated that a high chloride to sulfate mass ratio (CSMR) induces high galvanic currents and governs lead leaching incidences in distribution systems following coagulant changeovers (Dodrill and Edwards, 1995; Edwards et al., 1999; Dudi, 2004; Edwards and Triantafyllidou, 2007; Nguyen et al., 2010a; Nguyen et al., 2010c). When this research project was initiated, high CSMRs were merely hypothesized as the mechanism of attack and the link between the effect of coagulant changes and CSMR disturbances had not yet been undoubtedly linked to lead release concerns.

Galvanic Corrosion. Galvanic corrosion is induced when dissimilar metals come into contact with each other. In this study, galvanic corrosion is induced by the connection of a lead pipe to a copper pipe (Gregory, 1985; Dudi, 2004; Edwards and Triantafyllidou, 2007). For these specific metals, the galvanic series defines lead as the anode and copper as the cathode (Dudi, 2004). Unlike the case of uniform corrosion of an isolated lead pipe, the anodic and cathodic reactions are separated during galvanic corrosion. The copper surface acts as the cathode and is therefore reduced and protected, whereas the lead surface acts as the anode and it is oxidized and sacrificed. Galvanic corrosion increases the rate of lead corrosion above that which occurs in an isolated lead pipe and the rate of cathodic reactions such as oxygen reduction on the copper pipe surface, and therefore pH, is also increased (Dudi, 2004; Edwards and Triantafyllidou, 2007).

When samples are exposed to flowing water conditions, galvanic corrosion is not an issue because galvanic currents drop to low levels after only a few weeks of conditioning (Dudi, 2004). However, during stagnation, which is more representative of the conditions related to lead exposure in a household, dissolved oxygen (DO) is depleted over time and acidic conditions at the lead anode increase. Lead leaching is higher for galvanic corrosion due to the higher corrosion rates and the local pH drop at the surface of the lead material due to the production of Pb^{2+}, a lewis acid (Dudi, 2004). The local pH drop at the anode under stagnant conditions has been reported to be as low as 3-4 (Dudi, 2004; Edwards and Triantafillydou, 2007; and Nugyen, 2008). This pH range is low enough such that many corrosion inhibitors will not produce a protective scale on the surface of the anode (Dudi, 2004). Additionally, among other parameters, chloride and sulfate levels have been identified in prior research (e.g. Oliphant, 1983) as being highly influential in controlling lead corrosion rates under these circumstances (Triantafillydou, 2006).

Effect of CSMR. The suspicion of the effect of chloride to sulfate levels on lead release instances is not a new theory, as research relating the ratio of such chemicals to lead release dates back almost thirty years (Oliphant, 1983). It has been demonstrated that the quantities of chloride and sulfate in treated water can affect corrosion behavior in the distribution system. Oliphant (1983) and Gregory (1990) showed increases to galvanic corrosion currents and lead leaching when the CSMR ratio was high in bench-scale studies of lead leaching (Dudi, 2004). CSMR influences the conductivity, or oxidation reduction potential (ORP), of the water; where a high CSMR may cause an increase in water conductivity thereby increasing the rate of galvanic lead corrosion (Edwards and

Triantafyllidou, 2007). There have been several bench and case studies that demonstrated that a high CSMR could cause increased lead leaching into potable water (Gregory, 1985; Dodrill and Edwards, 1995; Dudi, 2004; Edwards and Triantafyllidou, 2007). The greatest impact of these anions is observed under low pH and low dissolved inorganic carbon conditions, such as those present under galvanic and stagnant conditions, where there is less hydroxide and carbonate species available to form complexes with Pb^{2+} (AWWA, 1996).

The presence of either chloride or sulfate alone tends to protect leaded materials when there is no galvanic connection to another metal. However, when a copper connection exists, chloride is drawn to the anode to maintain electroneutrality and stimulates the attack on lead pipe. At this low pH, chloride breaks down passivity by penetrating films through pores or defects easier then other ions such as sulfate (Reive and Uhlig, 2008). In doing so, chloride dissolves any coating or barrier previously on the lead surface and reacts with the lewis acid to form a soluble lead complex, $PbCl^+$, at these low pH conditions. $PbCl^+$ increases the exchange, or galvanic current, for anodic dissolution, therefore increasing lead leaching and preventing the formation of solid barriers on the lead surface (Reive and Uhlig, 2008; Clarke et al., 2008; Nguyen et al., 2008). Whereas, sufficient levels of sulfate are drawn to the anode and protects the pipe. $PbSO_{4(s)}$ is insoluble at the local pH drop occurring at the anode, therefore acting as a corrosion inhibitor by strengthening the arrangement of the corrosion protective layer on the lead surface (Dudi, 2004; Clarke et al., 2008; Nguyen et al., 2008).

When chloride and sulfate co-exist in a distribution system, the concentration of sulfate must be sufficient to overcome the counteractive effects of Cl^- and increase the strength of the corrosion scale (Edwards and Triantafllidou, 2007). Existing solubility models indicate that $PbSO_4$(s) can form on the surface of lead anodes despite the depression in pH when sulfate levels become high enough, tending to decrease leaching at the lead surface (Clarke and Edwards, 2008). On the other hand, solubility models predict that higher chloride increases lead solubility by formation of $PbCl^+$ under these low pH conditions. The critical CSMR level cited from multiple bench scale and full-scale studies that governs the effects of lead leaching is 0.5 mg of chloride per mg of sulfate (Gregory, 1985, Dodrill and Edwards, 1995). Above this level, galvanic corrosion of lead pipe is increased and below this threshold, lead leaching is mitigated.

According to DeSantis et al. (2009), the mineralogy of corrosion solids that develop at the lead-copper joints are different then the “normal” solids on the adjacent pipe surface (uniform lead corrosion environment). The dissimilar nature of these galvanic deposits indicates that the water quality in this zone differs from that of the bulk water quality in the distribution system. This agrees well with experimental observations of a large pH depression at the lead anode. Evidence of Cl^- and SO_4^{2+} corrosion products in this area confirm that there are apparent zones of aggression for these ions. Additionally, the mineralogy of the corrosion scales varied from system to system.

CHAPTER 3 MATERIALS AND METHODS

The purpose of this chapter is to describe raw source water characteristics, and the equipment and analytical procedures that are common to the experimental designs presented in **Chapters 5, 6, 7** and **8**. For clarity, materials and methods that are chapter specific will be described within that particular chapter, as well as any statistical analysis performed on the data.

This research involved the testing of Pockwock Lake raw water, which is treated at the JD Kline Water Supply Plant (JDKWSP) and provides drinking water for the greater Halifax area in Halifax, Nova Scotia, Canada.

3.1. POCKWOCK LAKE SOURCE WATER

The JDKWSP is a surface water treatment plant that draws water from the nearby Pockwock Lake. Pockwock Lake is in a protected watershed with no industrial or municipal waste influence. Low levels of pH, alkalinity, turbidity and organic carbon, as presented in Ta, characterize the raw water.

Table 3.1 Raw Source Water Characteristics

Analyte	Warm Water (10 to 20 - *ºC*) Range	Average	Cold Water (2 to 10 - *ºC*) Range	Average
Temperature - ***°C***	11.6 – 20.9	16.2	1.0 – 9.6	4.0
pH	4.9 – 5.4	5.1	4.9 – 5.3	5.0
Alkalinity – ***mg/L as*** $CaCo_3$	---	<1	---	<1
Turbidity - ***NTU***	0.28 – 0.49	0.39	0.29 – 0.46	0.37
UV_{254} **- cm**$^{-1}$	0.051 – 0.085	0.069	0.082 – 0.103	0.093
TOC - ***mg/L***	1.412 – 2.947	2.545	2.771 – 3.337	2.940
DOC - ***mg/L***	1.808 – 3.221	2.612	2.056 – 3.184	2.858
SUVA – m^{-1} ***per mg/L of DOC***	2.8 – 4.2	3.3	2.0 – 2.9	2.5

3.2. JD KLINE WSP OVERVIEW

The JDKWSP is a direct filtration treatment plant that employs pre-screening, oxidation, pre-chlorination, coagulation, hydraulic flocculation, direct filtration and chlorination. In the first pre-mix tank, lime is added to adjust the pH (9.6-10) for oxidation of iron and manganese using potassium permanganate ($KMnO_4$) and the second pre-mix tank provides additional mixing and detention time for this oxidation process. In the third pre-mix tank, carbon dioxide (CO_2) is added to adjust the coagulation pH (5.5-6.0) and alum is added as the primary coagulant at an average dosage of 8 mg/L. During the cold weather months (November through June), a cationic polymer is required to strengthen floc and maintain turbidity performance at an average dosage of 0.05 mg/L. Pre-chlorination occurs in the third pre-mix tank to control biofilm occurrence in the filters and is maintained at a post-filter total chlorine residual concentration of 0.05 mg/L. Next, water is delivered to four identical flocculation trains that contain three rows of parallel sets of cells (6 cells total). Tapered, hydraulic, flocculation occurs in these cells. Next, the flow is distributed between eight dual-media anthracite and sand filters. Finished water chemicals include the addition of chlorine for disinfection to maintain a total chlorine residual of 1.0 mg/L, sodium hydroxide to a finished water pH of 7.4, zinc/ortho polyphosphate for corrosion control (0.5 mg/L as PO_4) and hydrofluosilicic acid to provide fluoride addition for dental health.

3.3. PILOT PLANT DESCRIPTION

The JDKWSP pilot-scale plant consists of two identical, parallel treatment trains, both capable of simulating direct filtration or conventional treatment processes, manufactured by Intuitech, Inc (Salt Lake City, Utah). The pilot plant operates using Pockwock Lake raw water at a design flow rate of 15-L/min delivered to each treatment train. Each pilot train contains two treatment skids that contain coagulation, flocculation, sedimentation and filtration processes. A schematic and pictures of the pilot plant are presented in figures 3.1, 3.2 and 3.3.

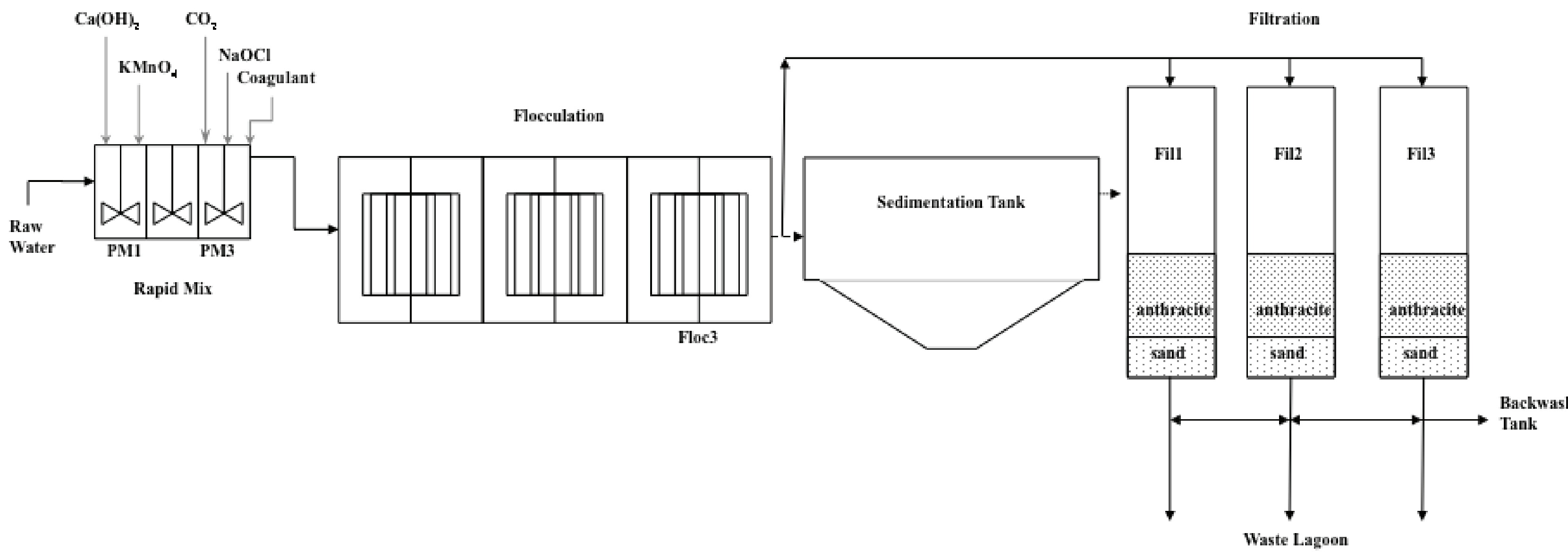


Figure 3.1 JDKWSP pilot plant treatment process schematic.

Figure 3.2 Photo of pilot plant coagulation, flocculation and sedimentation skid.

Figure 3.3 Photo of pilot plant filtration skid.

Raw water enters the coagulation/ flocculation skid into a series of three 11.3-L rapid mix tanks where chemical addition and mixing occur. The pilot plant has the capacity to feed 6 separate chemicals through peristaltic pumps to the chemical injection ports in the rapid mix tanks. From the rapid mix tanks, water flows into a series of three 189-L mechanical flocculation tanks with paddle mixers and then on to the optional sedimentation tank. The sedimentation tank is a 330-L basin with 30 adjustable plates, each with settling area of 0.1-m^2. The clarified water is collected in a settled water basin, after passing over the settling plates, and sludge can be pumped to a sampling port or to waste. If direct filtration is desired, the sedimentation tank can be bypassed and the flow is directed straight to the filtration skid.

The pilot plant was operated as a direct filtration plant for the duration of this research project. The filtration skid was built to match the bed depths and weir elevations of the full scale plant and contains a series of three 200-mm (8-inch) diameter dual-media filters containing 61-cm (2-ft) of anthracite and 30.5-cm (1-ft) of sand. There is no capability to add finished water chemicals at the pilot scale. The plant contains inline equipment to monitor pH, temperature, and turbidity at all critical process control points.

This fully automated plant has the flexibility to modify process variables such as chemical dosages, mixing energy, detention times, overflow rates, backwash sequences and filtration rates and the capability to extract water for analysis at any location throughout the treatment process. The pilot plant chemical system is capable of storing and feeding currently used chemicals and a wide spectrum of potential chemicals over a wide range of dosages.

3.4. ANALYTICAL PROCEDURES

Experimental parameters that were monitored throughout this research include pH, turbidity, TOC, DOC, UV_{254}, temperature, alkalinity, THMFP, HAAFP, and HPSEC.

General Water Quality Parameters. Throughout the duration of this research, reverse osmosis (RO) water was used for all cleaning and chemical stock preparations. All glassware was rinsed 3 times using RO water following cleaning. The RO water was obtained from a Milli-Q® purification system. Combination pH/ mV/ Temperature/ DO/ ISE and Conductivity meters (Accumet* XL 25 and XL 60 models) with plastic bodied, gel-filled, combination pH electrodes (Accumet Accu-Cap*) were used for pH readings. Three-point calibration (pH 4, 7, 10) was conducted each day. Alkalinity analysis was measured according to the potentiometric titration method 2320 (Standard Methods, 1998). A Hach 2100N laboratory turbidity meter was used for all bench-scale turbidity measurements.

The pilot plant contains inline Hach 1720E low range process turbidimeters to monitor filtered water turbidity and are located on the effluent stream of each individual filter on both pilot trains. When comparing filter run data between the pilot scale and FSP, in-line effluent turbidity data was extracted from HW's online monitoring system that was measured using Hach 1720 series low range process turbidimeters.

Organic Matter. TOC and DOC samples were collected head-space free in 40-mL pre-cleaned glass vials and preserved with concentrated phosphoric acid to a pH <2. Before sample collection, DOC samples were filtered through 0.45-µm polysulfone filter membrane (GE Water & Process Technologies) that had been pre-rinsed with 500-mL of RO water. TOC and DOC measurements were performed using a TOC-V CPH analyzer with a Shimadzu ASI-V autosampler and catalytically aided combustion oxidation non-dispersive infrared detector (NDIR) having a method detection limit of 0.08-mg/L (Shimadzu Corporation, Kyoto, Japan). For TOC and DOC analysis, the TOC analyzer operating conditions were as follows: TOC standard platinum catalyst; injector volume 50-µL; oven temperature 680°C; carrier gas flow 150 mL/min; potassium hydrogen phthalate standards 0 to 10-mg/L; correlation >0.99.

UV absorbance at 254-nm (UV_{254}) was measured using a HACH DR/4000 UV/VIS spectrophotometer (Hach Company, Loveland, CO) at a wavelength of 254 nm. Before sample collection, UV_{254} samples were filtered through 0.45-µm polsulfone filter membrane (GE Water & Process Technologies) that had been pre-rinsed with 500-mL of RO water. The nature of NOM in water samples was assessed by calculating the specific UV_{254} absorbance or SUVA value. SUVA is reported in units of m^{-1} of absorbance per mg/L and was calculated based on the following equation:

$$\text{SUVA } (m^{-1}/\text{mg/L}) = \frac{UV_{254}\ (cm^{-1})}{\text{DOC (mg/L)}} * \frac{100cm}{m}$$

Disinfection By-products. THMFP and HAAFP were analyzed using Standard Method 5710 (APHA, 2005) with minor modifications. Samples were buffered to a pH of 8 with borate and incubated for 24 hours following chlorination. Samples were dosed with 1.0-mg/L of buffered free chlorine to simulate current JDKWSP dosing conditions. THM and HAA samples were then prepared for gas chromatography analysis using liquid-liquid extraction (LLE) with pentane and methyl *tert*-butyl ether (MTBE), correspondingly. Gas chromatography using a Varian CP-3800 GC equipped with a VF-5 column and a Varian CP-8400 auto-sampler, coupled with an electron capture detector (GC-ECD) were used for the detection of THMs and HAAs according to the US EPA Methods 551.1 and 552.2. A a Varian CP-3800 GC equipped with a VF-5 column was used to analayze GC measurements. Samples were analyzed for four THM compounds: chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform. Samples were analyzed for 9 haloacetic acid analytes (HAA_9): monochloroacetic acid (MCAA), monobromoacetic acid (MBAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), bromochloroacetic acid (BCAA), dibromoacetic acid (DBAA), bromodichloroacetic acid (BDCAA), chlorodibromoacetic acid (CDBAA) and tribromoacetic acid (TBAA).

For THM determination, the gas chromatograph (GC) operating conditions were as follows: injector temperature 220°C; detector temperature 320°C; injection volume 1µL; flow rate 1 mL/min; sample injected at 50°C and held for 7 minutes, temperature increased to 115°C at a rate of 5 C/min with no hold, temperature increased to 295°C at a rate of 50 C/min and held for 0.5 minutes. A coefficient of determination R^2>0.95 was consistently achieved for the calibration curves for all four THM compounds.

For HAA determination, the gas chromatograph (GC) operating conditions were as follows: injector temperature 200°C; detector temperature 300°C; injection volume 1µL; flow rate 1 mL/min; sample injected at 35°C and held for 10 minutes, temperature increased to 65°C at a rate of 2.5 C/min with no hold, temperature increased to 85°C at a rate of 10 C/min with no hold, temperature is increased to 205°C at a rate of 20 C/min and held for 7 minutes. A coefficient of determination R^2>0.95 was consistently achieved for the calibration curves for all nine HAA analytes.

To validate the precision and accuracy of the THM and HAA methods, method blanks (RO water) and quality control (QC) samples (RO spiked with a known amount of standard mixture) were prepared for every 15 samples, for any given analysis. Recovery testing was conducted on QC samples and results were only accepted if QC recoveries were between 70 and 130%.

Size Exclusion Chromatography. Molecular size distribution of organic fractions was determined by HPSEC using high performance liquid chromatography (HPLC, Perkin Elmer Series 200). Prior to analysis, samples were brought to a pH of 3-7 and passed through a 0.45 µm filter membrane. Samples were evaluated using a TSK G3000SW column (7.5 mm X 300 mm) with a TSKgel SW guard column (7.5 mm X 70 mm). The media in the TSK column consists of silica with a pore size of 10 µm. These columns were connected to the Perkin Elmer Series 200 Autosampler and a UV/Vis detector set at UV 254 nm. Samples of 20 µl were injected and passed through the columns at a flow rate of 0.7 mL/min. A sample run time of 30 min was established, whereby all of the compounds in the sample had passed through the column. The molecular size calibration for the column was conducted using sodium polystyrene sulfonate standards (Scientific Polymer Products Inc) with different MWs: 14900, 7540, 5180 and 1530 Daltons (Da). A coefficient of determination (R^2) greater than 0.90 was consistently achieved.

Coagulant Properties. The coagulants used in this research were alum, ferric sulfate, a MBNS PACl and a HBNS ACH. The alum used in this research was supplied by General Chemical and the ferric sulfate, PACl and ACH were prepared by Kiemera Water Solutions Inc. Table 3.2 summarizes the properties of each coagulant used in this research.

Table 3.2 Coagulant Properties

	Alum	Ferric Sulfate	PACl (MBNS)	ACH (HBNS)
Trade Name	Liquid Alum	Ferric Sulfate Solution	PAX-18	PAX-XL 1900
Chemical Formula	$Al_2\ (SO_4)_3{*}14H_2O$	$Fe_2(SO_4)_3{*}9H_2O$	$Al_2(OH)_xCl_{6c}$-x $0<x>6$	$Al_2(OH)_5Cl{*}2H_2O$
Concentration Supplied (w/w)	48.5% $Al_2\ (SO_4)_3{*}14H_2O$	50 - 66% $Fe_2(SO_4)_3{*}9H_2O$	8 - 24% $Al_2(OH)_xCl_{6c}$-x $0<x>6$	30 – 60% $Al_2(OH)_5Cl.2H_2O$
% Al or Fe Supplied	4.2-4.4 as Al	12-13 as Fe	8.8 – 9.2 as Al	12.1 – 12.7 as Al
Specific Gravity	1.335	1.38-1.59	1.15 - 1.40	1.33 - 1.34
pH (neat)	2.0 – 2.4	<2	0.6 – 1.2	4.0 - 4.4
Basicity (%)	0	0	40 – 44	80
Sulfate (% wt)	23.4	---	0	0

CHAPTER 4 PAIRING A PILOT-PLANT TO A DIRECT FILTRATION WATER TREATMENT PLANT

4.1. ABSTRACT

Pilot-scale drinking water treatment plants are commonly used as investigative tools in the implementation of water quality research programs and to develop effective treatment solutions for full-scale facilities. A successful research program requires that a series of pilot proving experiments be completed to validate that a pilot plant can indeed be used as an effective research tool. This paper outlines experiments that were conducted to establish that statistically equivalent intermittent and finished water quality was demonstrated between pilot treatment trains and the full-scale plant (FSP). First, equivalence was successfully established between the two pilot trains using paired t-tests to confirm that the two trains were producing statistically equivalent water quality (e.g., pH, turbidity) while operating under identical operational and process conditions. Secondly, hypothesized mean differences and paired t-tests were effectively applied to confirm the water quality achieved following each treatment phase in the pilot plant mimicked the corresponding treatment process in the FSP. Successive trials demonstrated equivalence in multiple water quality parameters throughout the two treatment scales, including pH, UV_{254}, total organic (TOC), dissolved organic carbon (DOC), alkalinity and turbidity. The validation process successfully demonstrated that the pilot plant has the ability to reproduce full-scale behavior and that the results of the pilot research at this facility are in fact real of process changes that, when implemented at full scale, will successfully optimize the performance of the FSP.

4.2. INTRODUCTION

Pilot operations and pilot water treatment plants have been used as valuable pre-design tools that are constructed and operated with the intention of generating information to predict the behavior of proposed larger facilities. In recent years, pilot plants have also been erected to facilitate the optimization of current treatment processes, in which case they become more of a calibration tool and allow utilities to test and confirm treatment optimization options before full-scale implementation is attempted. Thus, pilot-plants serve to close the gap between bench and full-scale studies.

Another key advantage of a pilot plant is its ability to study multi-objective issues simultaneously and confirm the effects of variables acting independently and in combination throughout the treatment processes. Identical treatment trains are essential during pilot studies to ensure that the effects of changing raw water characteristics are eliminated by continuously operating one side of the plant such that the same finished water quality as the full-scale plant (FSP) is continuously achieved (Anderson et al., 1993; Bonnet et al., 1996; Piirtola, 1999; Andrews et al., 2005). Following pilot plant installation, both commissioning and proving processes are essential to ensure the plant is installed and operating according to design specifications and also to confirm that equivalent influent, intermittent and finished water quality can be demonstrated between both the parallel pilot trains and the FSP (Anderson et al., 1993; Andrews et al., 2005).

The pilot-plant proving process involves operating the commissioned pilot plant and making the necessary adjustments to ensure the aforementioned criteria are achieved.

This validation procedure is completed to make certain the results of the pilot research are representative of process changes that, when implemented at full scale, will successfully optimize the performance of the plant (Anderson et al., 1993; Bonnet et al., 1996; Piirtola, 1999; Andrews et al., 2005). Therefore, several control experiments must be carried out to establish the pilot and FSP treatment processes produce statistically equivalent results. First, equivalence must be established between the two pilot trains using statistical tests to confirm that the two trains are producing equivalent water quality while operating under identical operational and process conditions. Secondly, the water quality achieved following each treatment phase in the individual pilot plants must mimic the water quality produced in the corresponding treatment process in the FSP. Both of these proving procedures must be successfully completed before detailed optimization experiments can be undertaken and the intended research projects commence.

Objectives. This paper provides details concerning the proving process of a drinking water pilot treatment plant. Specifically, it outlines the experimental and statistical validation procedures used to verify that the pilot treatment process replicates that of a direction filtration plant and that the two pilot treatment trains produced equivalent water quality. A particular challenge of this validation process was the inherent difference in flocculation mixing technologies between the pilot plant mechanical mixers and the full-scale hydraulic flocculators. It is the aim of this paper to provide utilities with a framework for conducting in-house pilot proving trials at their facilities.

4.3. MATERIALS AND METHODS

Source Water. This project was conducted at the JD Kline Water Supply Plant (JDKWSP) in Halifax, Nova Scotia, Canada. Low levels of pH, alkalinity, turbidity and organic carbon characterize the raw water. Table 4.1 outlines the source water characteristics during the pilot proving trials.

JD Kline Water Supply Plant. The JDKWSP is a direct filtration treatment plant that employs pre-screening, oxidation, pre-chlorination, coagulation, hydraulic flocculation, direct filtration and chlorination. In the first pre-mix tank, lime is added to adjust the pH (9.6-10) for oxidation of iron and manganese using potassium permanganate ($KMnO_4$) and the second pre-mix tank provides additional mixing and detention time for this oxidation process. In the third pre-mix tank, carbon dioxide (CO_2) is added to adjust the coagulation pH (5.5-6.0) and aluminum sulfate (alum) is added as the primary coagulant at an average dosage of 8-mg/L. During the cold weather months (November through June), a cationic polymer is required to strengthen floc and maintain turbidity performance, at an average dosage of 0.05-mg/L. Pre-chlorination also occurs in the third pre-mix tank to control biofilm occurrence in the filters and is maintained at a post-filter total chlorine residual of 0.05-mg/L. Next, water is delivered to four identical flocculation trains that contain three rows of parallel sets of cells (6 cells total). Tapered, hydraulic, flocculation occurs in these cells. Next, the flow is distributed between eight dual-media anthracite and sand filters. Finished water chemicals include the addition of chlorine for disinfection to maintain a total chlorine residual of 1.0-mg/L, sodium hydroxide to a finished water pH of 7.4, zinc/ortho polyphosphate for corrosion control

(0.5-mg/L as PO_4) and hydroflurosilicic acid to provide fluoride addition for dental health.

Pilot Plant Description. The JDKWSP pilot-scale plant consists of two identical, parallel treatment trains, both capable of simulating direct filtration or conventional treatment processes, manufactured by Intuitech, Inc (Salt Lake City, Utah). The pilot plant uses Pockwock Lake as its raw water source and has a design flow rate of 15-L/min delivered to each treatment train. Figure 4.1 shows a process schematic of the treatment processes at the JDKWSP pilot plant. Each pilot train contains two treatment trains that contain coagulation, flocculation and filtration processes. Raw water enters the coagulation/ flocculation skid into a series of three 11.3-L rapid mix tanks where chemical addition and mixing occur. The pilot plant has the capacity to feed 6 separate chemicals through peristaltic pumps to the chemical injection ports in the rapid mix tanks. From the rapid mix tanks, water flows into a series of three 189-L mechanical flocculation tanks with paddle mixers and then on to the optional sedimentation tank. The sedimentation tank is a 330-L basin with 30 adjustable plates, each with settling area of 0.1-m^2. The clarified water is collected in a settled water basin, after passing over the settling plates, and sludge can be pumped to a sampling port or to waste. If direct filtration is desired, the sedimentation tank can be bypassed and the flow is directed straight to the filtration skid.

The pilot plant was operated as a direct filtration plant for the duration of this research project. The filtration skid was built to match the bed depths and weir elevations of the full scale plant and contains a series of three 200-mm (8-in) diameter dual-media filters containing 61-cm (2-ft) of anthracite and 30.5-cm (1-ft) of sand. There is no capability to add finished water chemicals at the pilot scale.

This fully automated plant has the flexibility to modify process variables such as chemical dosages, mixing energy, detention times, overflow rates, backwash sequences and filtration rates and the capability to extract water analysis at any location throughout the treatment process. The pilot plant chemical system is capable of storing and feeding currently used chemicals and a wide spectrum of potential chemicals over a range of dosages. The plant contains inline equipment to monitor pH, temperature, turbidity and particle counts at all critical process control points.

4.3.1. Experimental Procedures

The pilot proving methodology was based on both the successes and lessons learned from pilot studies carried out in Ottawa and Windsor, Ontario (Anderson et al., 1993).

Comparison of Pilot Treatment Trains. The first proving step is to ensure equivalence is established between the two pilot trains using a paired t-test to confirm that the two trains are producing statistically equivalent water quality while operating under identical operational and treatment conditions (Anderson et al., 1993). These operating conditions were chosen to simulate the FSP to the extent possible, such that this initial proving stage could provide some insight to the second task of proving, which is adjusting the pilot trains to simulate the full scale performance. The selected operating conditions were synchronized between the parallel pilot trains.

Table 4.2 presents the operating conditions of the parallel pilot trains and FSP during the pilot proving trials (e.g., chemical dosages, mixing speeds, retention times). Since the pilot plant utilizes mechanical mixers, low G-values were chosen to emulate, to the extent possible, the inadequate hydraulic mixing intensities identified through computational fluid dynamics (CFD) modeling in the FSP (Vadasarukkai and Gagnon, 2010). The backwash procedures of filters 1 and 2 on each pilot train were set to simulate the FSP backwash procedure, whereas filter 3 was programmed to simulate an extended terminal sub-fluidization wash (ETSW) on each train. During pilot proving experiments, the filter loading rates were set approximately 40% higher than the FSP filter loading rates so that experimental time was reduced (Table 4.2).

Each pilot-to-pilot proving trial corresponded with a 48-h filter run time in the pilot plant. A filter run time of 48-h in the pilot plant produced the same number (360) of unit filter run volumes (UFRV) as an 80-hr filter run in the FSP. The trials began with a backwash of each pilot filter and 1-L grab samples were collected at 10-mins, 4-h, 24-h, 28-h, and 48-h into the filter run. The 10-min sample time was intended to encompass the water quality during the ripening phase, which was an important filtration step to simulate between the pilot trains. Grab samples were collected from the raw water inlet (RW), post-coagulation (PM3), post-flocculation (Floc 3), and post-filtration (Fil-1, Fil-2 and Fil-3) on each pilot train (Figure 4.1). The grab samples were analyzed for a range of response parameters including pH, UV_{254}, turbidity, TOC, DOC and alkalinity. Additionally, in-line turbidity data for effluent filtered water was collected for each pilot filter.

Paired t-testing was used to determine if the two pilot trains were operating identically. Assessing statistical equivalence using paired t-tests at the 0.05 level of significance is commonly used for validating parallel treatment system performance and also for comparing population differences between the parallel treatment systems during research trials (Anderson et al., 1993; Piirtola et al., 1999; Andrews et al., 2005). Paired t-testing eliminates uncontrolled disturbances, such as changing raw water quality, by ensuring that the uncontrolled factors contribute equally to both of the paired observations (MacBerthouex and Brown, 2002). A response parameter or data point from pilot plant train 1 (PP1) was directly compared with the corresponding data (location and time) collected from pilot plant train 2 (PP2). If the pilot trains were producing equivalent water quality, then ideally the expected difference between the two values forming the data pair would be zero (Anderson et al., 1993; Andrews et al., 2005). Pilot trials continued until the results were deemed not significantly different at the 95% confidence interval.

Comparison of Pilot Plant and Full Scale Performance. After demonstrating equivalence between the two sides of the pilot plant, the next step was to prove that the pilot plant and full-scale treatment systems were achieving the same intermittent and finished water quality (Anderson et al., 1993; Bonnet et al., 1996; Andrews et al., 2005).

During this proving task the FSP filters were achieving 72-hr filter runs. Due to differences in filter loading rates, a 72-hr filter run time in the FSP was equivalent to a 43-hr filter run time in the pilot or approximately 32 million liters of water per square meter of filter media (ML/m^2) being processed by each scale of filter. The trials began with a simultaneous backwash of each pilot filter and the FSP filter to eliminate the effects of changing water quality. From the pilot plant, 24-h and 28-h 1-L grab samples were collected, which represented 180 and 210 UFRV, respectively. 28-h and 48-h 1-L grab samples were collected in the FSP, which corresponded to 125 and 214 UFRV, respectively. The 24-h pilot and 28-h FSP samples and 28-h pilot and 48-h FSP samples were compared during the statistical analysis. For each treatment scale, grab samples were taken from the raw water inlet (RW) and the post-coagulation (PM3), post-flocculation (Floc3), and post-filtration (Fil) stages in PP2 and the FSP. The grab samples were analyzed for a range of response parameters including pH, UV_{254}, TOC, and DOC. Additionally, in-line turbidity data for effluent filtered water was collected for each filter.

Since equivalence between the two pilot trains was completed first, for the pilot-to-FSP proving stage, equivalence was only determined between one pilot train, PP2, and the FSP. The only difference between operating conditions used in pilot-to-pilot proving and the pilot-to-FSP trials were the backwash procedures used. During pilot-to-FSP proving trials, the full-scale filter backwash procedure was modified from the plants original design conditions to optimize ripening profiles and a 1-h rest period was added to the end of the normal backwash procedure. Thus, a 1-h rest period was inserted at the end of the normal backwash cycle in PP2. Of the eight FSP filters, the same filter was sampled throughout the proving process to remove any unnecessary variability in filter performance.

To determine equivalence, as described by Anderson et al. (1993), a set of performance criteria was established based on acceptable variation limits between the pilot and full-scale systems, since it is generally recognized that performance may not be exactly duplicated between the two scales. Pilot-to-FSP trials were repeated until the pilot plant was producing statistically equivalent water quality to the FSP.

4.3.2. Analytical Procedures

Throughout the duration of this research, RO water was used for all cleaning and chemical stock preparations. All glassware was rinsed 3 times using RO water following cleaning. The RO water was obtained from a Milli-Q® purification system. Combination pH/ mV/ Temperature/ DO/ ISE and Conductivity meters (Accumet* XL 25 and XL 60 models) with plastic bodied, gel-filled, combination pH electrodes (Accumet Accu-Cap*) were used for pH readings. Three-point calibration (pH 4, 7, 10) was conducted each day. Alkalinity was carried out according to the potentiometric titration method 2320 (Standard Methods, 1998). A Hach 2100N laboratory turbidity meter was used for all bench-scale turbidity measurements.

The pilot plant contained inline Hach 1720E low range process turbidimeters to monitor filtered water turbidity and are located on the effluent stream of each individual filter on both pilot trains. When comparing filter run data between the pilot scale and FSP, in-line effluent turbidity data was extracted from HW's online monitoring system that was measured using Hach 1720 series low range process turbidimeters.

TOC and DOC samples were collected head-space free in 40-mL pre-cleaned glass vials and preserved with concentrated phosphoric acid to a pH <2 and measurements were performed using a TOC-V CPH analyzer with a Shimadzu ASI-V autosampler and catalytically aided combustion oxidation non-dispersive infrared detector (NDIR) having a method detection limit of 0.08 mg/L (Shimadzu Corporation, Kyoto, Japan). UV absorbance at 254-nm (UV_{254}) was measured using a Hach DR/4000 UV/VIS spectrophotometer (Hach Company, Loveland, CO) at a wavelength of 254 nm. Before sample collection, UV_{254} and DOC samples were filtered through a 0.45 μm filter membrane (GE Water & Process Technologies) that had been pre-rinsed with 500-mL of RO water.

4.4. RESULTS AND DISCUSSION

The proving process took several months to complete, due to the variability of parameters beyond the control of the operator, such as seasonal variations in temperature and organics loading, flow rate variations, chemical feed issues and general operational issues not identified during the commissioning process. Before pilot proving began, the operating conditions of the pilot plant were set to mimic, to the extent possible, the operating conditions of the FSP. Setting and maintaining target pH goals in the pilot plant was the most challenging operational task, due to chemical feed issues in the pilot plant which were in a large part due to the challenges of feeding lime at the pilot scale. Such challenges included adequately mixing lime slurries, differences in lime quality and feed lines clogging, which inevitably lead to inconsistent feed concentrations caused by the aforementioned issues. Such pre-proving tasks are normal when you consider the amount of time a FSP takes to be properly commissioned and operate within design conditions.

Comparison of Pilot Plant Treatment Trains. In total, four pilot-to-pilot proving trials were completed during the months of February through March, 2008. Initially, a statistical analysis was conducted on each baseline parameter measured utilizing a paired t-test analysis. Although the results from the paired t-test were generally favourable at the 95% confidence interval (Table 4.3), a small number of parameters (6 of 30) did fail this test. Contrastingly, in a pilot plant validation study completed by Andrews et al. (2005), the majority of parameters measured between the parallel trains were not statistically equivalent at the 0.05 level of significance.

The statistical analysis did not incorporate measurement error, therefore a residuals analysis was conducted for each bench-scale parameter measured and these errors were checked for randomness by plotting the residuals (MacBerthouex and Brown, 2002). Profiles of the residuals for representative proving parameters measured (pH and DOC) are presented in Figure 4.2. Residuals plots suggested that the errors were random and, additionally, the average of residuals for each measured parameter was zero (MacBerthouex and Brown, 2002). The upper and lower boundary lines shown in Figure 4.2 represent two standard deviations of the residual population mean. These boundaries were determined for each analyte measured (Table 4.3) and were used to assess the system tolerance between the pilot-trials by inserting these limits as the hypothesized mean differences in the paired t-tests.

All parameters measured during pilot-to-pilot proving trials markedly passed the revised paired t-test analysis using the measurement errors as the hypothesized mean differences (Table 4.3). Therefore, the pilot-plants were found to be statistically equivalent for pH, UV_{254}, TOC, DOC, and alkalinity. A comparison of the mean differences between the paired pilot samples for pH and DOC over the duration of the pilot-to-pilot proving process is provided in Figure 4.3. Overall, the mean differences between paired samples measured for each parameter were very minor at each stage of the treatment process (Table 4.3) and the differences reported were below 0.1-mg/L for TOC and DOC, 0.002-cm^{-1} for UV-absorbance, 0.1 units for pH and 1.0-mg/L for alkalinity. In addition, the magnitudes of the mean differences reported in this study are comparable or less than those reported by Andrews et al. (2005).

Filter performance was evaluated through the analysis of online filter effluent turbidity data collected for each of the three pilot filters on both pilot treatment trains. Effluent turbidity data was extracted from Halifax Water's online monitoring system at 1-minute intervals over the duration of each filter run. One complete filter run represents the time from which the filter is put into service until it is taken offline for backwashing; therefore, one filter run includes the ripening phase, steady-state filtration operation and turbidity breakthrough.

Figure 4.4 presents turbidity profiles for all three pilot filters for a representative pilot-to-pilot proving trial. Again, the backwash procedures of filters 1 and 2 on each pilot train were set to simulate the FSP backwash procedure, whereas filter 3 was programmed to simulate an ETSW procedure on each train. The duration of the filter ripening stage and total filter run lengths (FRLs) are the key stages of a filter profile that would be most affected by water quality differences between the pilot trains. Therefore, a snapshot of the ripening stage of each turbidity profile presented in Figure 4.4(a) is shown in Figure 4.4(b) and was used as another means of assessing the similarity of the pilot filters.

Based on a visual comparison, turbidity profiles are similar and were reproducible for corresponding filters on PP1 and PP2, which is highlighted in the ripening profiles, steady state turbidity readings, and total filter run times. The brief change in steady-state turbidity readings for PP2 filters at approximately 20 hours into the filter run was due to a clog in the lime chemical feed line, but this issue was rectified in time to get the filters back to steady-state conditions before the trial was lost. Temporary lime line clogging occurred during most proving trials and this operational issue was rectified by upgrades to the lime feed system after proving trials were complete.

Since turbidity profiles encompass an extensive data set with several variations of effluent quality trends throughout (filter ripening stage, normal effluent production levels, filter breakthrough, and intermittent turbidity spikes), condensing this data into one number (i.e., an average) for effluent comparison purposes, does not give a complete representation of the data (Hargesheimer et al., 1998). Percentile ranking is a valuable indicator of the performance of individual filters (Hargesheimer et al., 1998) and was used to provide a statistical analysis of the effluent turbidity trends during pilot-to-pilot proving. Percentile ranking of the data summarizes the data into percentile ranking groups that represent the turbidity profile over the entire filter run and provides an effective means of condensing the data into a format that effectively summarizes the filter performance. The data from each filter run was broken down into the corresponding 10^{th}, 50^{th}, 90^{th}, 95^{th}, and 98^{th} percentiles to summarize the performance of each filter (Hargesheimer et al., 1998). Next, the individual percentile turbidity values from each filter run were pooled to obtain an average percentile ranking for each filter over the four proving trials completed.

Figure 4.5 presents the average probability plots for each individual pilot filter throughout the four pilot-to-pilot proving trials. The corresponding probability statistics are presented in Table 4.4. The similar trends observed in these probability plots and statistics provides further evidence there are no significant differences between the effluent turbidities between pilot treatment trains.

Comparison of Pilot Plant and Full Scale Performance. In total, five pilot-to-FSP proving trials were completed during May through August, 2008, comparing the influent, intermittent and effluent water quality between PP2 and the FSP. During pilot-to-FSP proving trials, the pilot plant was operated under identical "same day" operating conditions as the FSP (Table 4.2). Operational changes were made in the pilot plant only to match a simultaneous change in FSP operating conditions. The operating conditions modified throughout these trials were pre-oxidation pH and coagulation pH/dosage targets.

Although identical operating conditions were maintained, previous pilot proving experiences indicated that this alone would not produce similar finished water quality between the two process scales; and that, in fact, the water quality may be substantially different (Anderson et al., 1993; Andrews et al., 2005). According to Anderson et al. (1993), there are two reasons this occurs, despite the fact that the operating conditions were matched as closely as possible. The first factor involves assumptions that the pilot plant will perform identically when operating under the same conditions as the FSP despite the fact that it has only been operating for a limited amount of time, and the second factor involves scale down problems (i.e., hydraulic versus mechanical flocculation). Therefore, hypothesized mean differences, as shown in Table 4.5, were used as a means of evaluating pilot-to-FSP performance (Anderson et al., 1993; Andrews et al., 2005). These performance benchmarks were determined through steering committee discussions and consultations with pilot operators prior to the commencement of these proving trials.

Paired t-tests were applied to the pilot and FSP data with the pre-determined hypothesized limits inserted as the hypothesized mean differences (Anderson et al., 1993). Although a significant portion of the parameters passed under these conditions, 6 out of 20 parameter pairs did not (Table 4.5). In addition, 3 of the 5 filter effluent parameters failed this test, which is perhaps the most important stage of the process to achieve equivalent water quality. The pre-determined hypothesized mean differences applied in this study were significantly more aggressive than those used by Anderson et al. (1993) and Andrews et al. (2005). Specifically, the acceptable limits of difference were 10% for UV-absorbance and 10 to 20% for organic matter removal in the aforementioned studies and the overall results were favourable under these less stringent limits (Anderson et al., 1993; Andrews et al, 2005). Based on the large measurement errors realized through the pilot-to-pilot proving data analysis, it was decided that performing a residuals analysis on the pilot-to-FSP results would provide a basis for a more realistic set of performance benchmarks to be employed.

As with pilot-to-pilot proving, measurement error limits were determined for each parameter measured (Table 4.5) and were used to assess the system tolerance between the pilot and FSP data by inserting these limits as the hypothesized mean differences in the paired t-tests. All parameters measured during pilot-to-FSP proving trials passed the revised paired t-test analysis and the pilot treatment process and FSP were found to be statistically equivalent for pH, UV_{254}, TOC and DOC. Overall, the filtered water mean differences between pilot and full-scale treatment were less than 10% for TOC (<0.15-mg/L) and DOC (<0.08-mg/L), 15% for UV-absorbance (<0.004-cm^{-1}), and 0.1 units for pH. The magnitudes of the mean differences between the two scales of treatment reported in this study are comparable or less than those reported by Andrews et al (2005).

Filter effluent quality was used to assess the turbidity equivalence between the pilot versus FSP data. Filter performance was evaluated through the analysis of online filter effluent turbidity data. Effluent turbidity data was extracted at 1-min intervals over the duration of each filter run. Figure 4.6 presents the turbidity profiles of a representative pilot-to-FSP proving trial. Steady-state turbidity readings are well within the 0.05-NTU hypothesized mean difference limits. However, the ripening stage turbidities and filter run time criteria are not equivalent between the treatment scales. The main reason for these discrepancies is the inherent differences in flocculation mixing regimes between the pilot and FSP (mechanical versus hydraulic mixing). Although not quantified, such differences can lead to differences in the size and strength of floc particles entering the filters. On average, flocculated water turbidities were 0.32-NTU higher in the pilot plant and this difference was as high as 0.8-NTU during some trials. These differences in post-flocculation water quality are further highlighted by the differences reported in TOC and UV-absorbance levels between the treatment scales (Table 4.5). Similar to results reported by Anderson et al (1993), these differences in particle loading to the pilot filters didn't affect the ability of the pilot filter to reduce the turbidity to FSP levels, however the ripening period and filter run times suffered. The ripening turbidity spikes were consistently higher in the pilot filters, however the duration of the ripening sequence was very similar based on equivalent UFRVs (Figure 4.6). Additionally, the FRL was shorter in the pilot plant due to the differences in particle loading; the pilot plant FRL was defined by turbidity breakthrough, whereas the FSP was limited by filter headloss.

Since steady-state turbidity values were within the 0.05-NTU limit applied (90th percentile <0.02-NTU), it was deemed unnecessary to implement changes to the pilot plant operating conditions until the ripening stages and FRLs were equivalent. These differences in mixing regimes between the two scales provided a factor of scale between the pilot and full-scale facilities and will be drawn on when recommending process optimization upgrades in the full-scale system. Additionally, CFDs was used to evaluate the mixing regimes currently achieved by the hydraulic flocculation tanks at the JDKWSP (Vadasarukkai, 2010). It was concluded that a combination of short-circuiting and inadequate mixing regimes are occurring in these tanks; a direct result of a dated design and the plant not achieving design flow rates in the hydraulic flocculators. Experiments are currently being conducted to examine opportunities for an alternate mixing technology and process operations to achieve improved particle and organic matter removal.

Post-proving Pilot Challenges. The only notable post-proving issues experienced with pilot operations corresponded with cold-water temperatures (<10ºC), during which the FSP traditionally supplements their process with a cationic polymer to maintain turbidity performance. Due to the efficiency of the mechanical mixers, adding a polymer to the pilot treatment process presented high particle loading to the filters and filtered water turbidities were unacceptable. This issue was mitigated by increasing the pilot alum dose to approximately 10.5-mg/L and foregoing the use of a polymer in the pilot treatment process, which brought the filter effluent turbidities to within acceptable levels.

4.5. CONCLUSIONS

A series of pilot proving trials were completed and successful in confirming that statistically equivalent water quality was being produced by the parallel pilot treatment trains and the FSP. Both the pilot-to-pilot and pilot-to-FSP proving trials demonstrated equivalence in multiple water quality parameters throughout the two treatment scales.

Correspondence was established between the two pilot trains by applying paired t-testing techniques to the water quality data produced by the parallel treatment trains. Using the measurement error as a basis for train comparison in paired t-tests, the pilot plants were found to be statistically equivalent based on pH, UV_{254}, TOC, DOC and alkalinity measurements taken at key locations throughout the treatment process. Filtered water turbidity was evaluated by using percentile plotting and visual comparisons of filtered water turbidity profiles. Turbidity profiles were similar and reproducible for corresponding filters on each pilot train, which was highlighted by equivalence throughout the ripening phase, steady-state trends and filter breakthrough profiles.

Paired t-testing using the pre-determined hypothesized mean differences was not a successful means of determining equivalence between the pilot and FSP treatment trains in this study. Although these paired t-test results were generally favorable for the pilot versus FSP data, there were a few parameters that failed this test. In retrospect, the preset acceptable limits were too stringent when you account for the magnitude of measurement errors realized during these proving studies for pH, TOC, DOC and UV_{254}. Inserting the measurement error limits as the revised mean differences in the paired t-tests was deemed a more reasonable approach and each parameter passed using these revised performance benchmarks at each sample location. In future pilot proving studies, it is recommended that the measurement errors for each parameter be considered in order to set achievable and acceptable deviations between pilot and full-scale performance. Contrastingly, the hypothesized mean difference of 0.05-NTU for filter effluent turbidity was not strict enough and a more appropriate performance benchmark for turbidity differences would have been 0.02-NTU.

The pilot proving process demonstrated that the pilot plant has the ability to reproduce water quality outcomes from the full-scale plant and that the results of the pilot facility are representative of process changes that will be used to optimize the performance of the FSP. Differences in mixing regimes between the two scales was the main factor of scale identified between the pilot and full-scale facilities and will be drawn on when recommending process optimization upgrades in the full scale system. Although this proving process was successful, it is important to periodically validate the water quality being produced between parallel pilot treatment trains and to continuously ensure that the control pilot train is producing equivalent water quality as the FSP, especially during particularly challenging treatment events (i.e., heavy organics loading and cold weather operations).

Table 4.1 Raw source water characteristics during the pilot proving trials.

Analyte	Pilot to Pilot[1]		Pilot to FSP[2]	
	Range	Average	Range	Average
Temperature - *°C*	4.4 – 7.9	6.2	10.1 – 23.4	17.2
pH	4.0 – 5.0	4.8	4.8 – 5.2	4.9
Alkalinity – *mg/L as $CaCo_3$*	---	<1	---	<1
Turbidity - *NTU*	0.32 – 0.54	0.42	0.38 – 0.99	0.56
UV_{254} - cm^{-1}	0.100 – 0.011	0.105	0.070 – 0.100	0.085
TOC - *mg/L*	2.25 – 3.41	2.78	2.15 – 3.08	2.62
DOC - *mg/L*	2.28 – 3.16	2.28	2.02 – 3.07	2.60

[1]Pilot-to-pilot proving trials were conducted from February through March, 2008.
[2]Pilot-to-FSP proving trials were conducted from May through August, 2008.

Table 4.2 Pilot plant and FSP operating conditions during pilot proving trials.

Parameter	Unit	Full Scale Plant	Pilot Plant
Flowrate	*as noted*	98 MLD	15 L/min
Target Pre-oxidation pH	*pH*	10.1	10.1
Potassium Permanganate Dosage	*mg/L*	0.015	0.015
Target Coagulation pH	*pH*	5.7	5.7
Alum Dosage	*mg/L*	8	8
Post-filter Chlorine Residual	*mg/L*	0.05	0.05
Polymer Dosage	*mg/L*	0.055	0.055
Rapid mix blade speed	*rpm*	45	192
Rapid mix velocity gradiant	s^{-1}	147	263
Rapid mix G•t value	*dimensionless*	11844	11844
Flocculation velocity gradiant	s^{-1}	---	30, 20, 10
Anthracite effective size	*mm*	0.89	0.89
Anthracite uniformity coefficient	*mm*	1.67	1.67
Anthracite depth	*mm*	609.6	609.6
Sand effective size	*mm*	0.52	0.52
Sand uniformity coefficient	*mm*	1.53	1.53
Sand depth	*mm*	304.8	304.8
Filter hydraulic loading rate	$L/hr/m^2$	4,500	7,500

Table 4.3 Paired t-test results for pilot-to-pilot proving trials.

Parameter	Paired t-test Limits	Paired T-test Results: Raw Water (RW)	Post-Coagulation (PM3)	Post-Flocculation (Floc3)	Filtered Water (Fil1)	Filtered Water (Fil2)	Filtered Water (Fil3)
95% Confidence Interval (CI)							
pH	95% CI	Pass	**Fail**	Pass	**Fail**	Pass	Pass
TOC – *mg/L*	95% CI	Pass	Pass	Pass	Pass	Pass	Pass
DOC – *mg/L*	95% CI	Pass	Pass	Pass	Pass	Pass	Pass
UV_{254} – *cm^{-1}*	95% CI	**Fail**	Pass	Pass	**Fail**	Pass	**Fail**
Alkalinity – *mg/L as $CaCO_3$*	95% CI	Pass	Pass	Pass	Pass	Pass	**Fail**
Revised Mean Differences (Measurement Error[1])							
pH	± 0.19	Pass *(0.03)*[2]	Pass *(0.07)*	Pass *(0.03)*	Pass *(0.05)*	Pass *(0.05)*	Pass *(0.04)*
TOC – *mg/L*	± 0.38	Pass *(0.102)*	Pass *(0.032)*	Pass *(-0.001)*	Pass *(0.010)*	Pass *(-0.064)*	Pass *(-0.059)*
DOC – *mg/L*	±0.31	Pass *(0.124)*	Pass *(-0.029)*	Pass *(0.068)*	Pass *(-0.059)*	Pass *(0.021)*	Pass *(0.022)*
UV_{254} – *cm^{-1}*	± 0.006	Pass *(-0.001)*	Pass *(0.001)*	Pass *(0.002)*	Pass *(-0.001)*	Pass *(-0.001)*	Pass *(-0.002)*
Alkalinity – *mg/L as $CaCO_3$*	± 2.3	Pass *(0.20)*	Pass *(0.79)*	Pass *(0.65)*	Pass *(-0.09)*	Pass *(0.15)*	Pass *(0.71)*

[1] The measurement error represents two standard deviations of the residual population mean for each response parameter.
[2]Values in parentheses represent the mean difference between PP1 and PP2 measurements for each response parameter.

Table 4.4 Average filtered turbidity percentile statistics for each pilot filter during pilot-to-pilot proving trials.

	Average Turbidity Summary					
	Filter 1		Filter 2		Filter 3	
Percentile	**PP1**	**PP2**	**PP1**	**PP2**	**PP1**	**PP2**
10th	0.199	0.207	0.221	0.183	0.205	0.197
50th	0.223	0.254	0.248	0.227	0.229	0.247
90th	0.319	0.352	0.357	0.319	0.328	0.338
95th	0.383	0.427	0.412	0.399	0.380	0.412
98th	0.508	0.520	0.531	0.461	0.479	0.491

Table 4.5 Paired t-test results for pilot-to-FSP proving trials.

Parameter	t-test Limits	Paired T-test Results: Raw Water (RW)	Post-Coagulation (PM3)	Post-Flocculation (Floc3)	Filtered Water (Fil)
		Hypothesized Mean Differences			
pH	Within 0.1 units	Pass *(0.03)*[1]	**Fail *(0.16)***	Pass *(0.07)*	Pass *(0.10)*
TOC – *mg/L*	Within 5% of FSP	Pass *(3.8%)*	Pass *(-0.8%)*	Pass *(4.8%)*	**Fail *(-8.3)***
DOC – *mg/L*	Within 5% of FSP	Pass *(1.7%)*	Pass *(-4.3%)*	Pass *(-0.2%)*	**Fail *(-5.2)***
UV_{254} – cm^{-1}	Within 5% of FSP	Pass *(-0.8%)*	**Fail *(-9.1%)***	**Fail *(-24%)***	**Fail *(-14%)***
Turbidity - *NTU*	± 0.05 NTU	Pass	Pass	Pass	Pass
		Revised Mean Differences (Measurement Error[2])			
pH	Within 0.19 units	Pass *(0.03)*	Pass *(0.16)*	Pass *(0.07)*	Pass *(0.10)*
TOC – *mg/L*	Within 0.38	Pass *(0.115)*	Pass *(0.032)*	Pass *(0.269)*	Pass *(-0.132)*
DOC – *mg/L*	Within 0.31	Pass *(0.075)*	Pass *(-0.076)*	Pass *(-0.006)*	Pass *(-0.075)*
UV_{254} – cm^{-1}	Within 0.006	Pass *(-0.001)*	Pass *(-0.002)*	Pass *(-0.006)*	Pass *-0.004)*
Turbidity - *NTU*	± 0.05 NTU	Pass	Pass	Pass	Pass

[1]Values in parentheses represent the mean difference between the pilot and FSP measurements for each response parameter.
[2]The measurement error represents two standard deviations of the residual population mean for each response parameter.

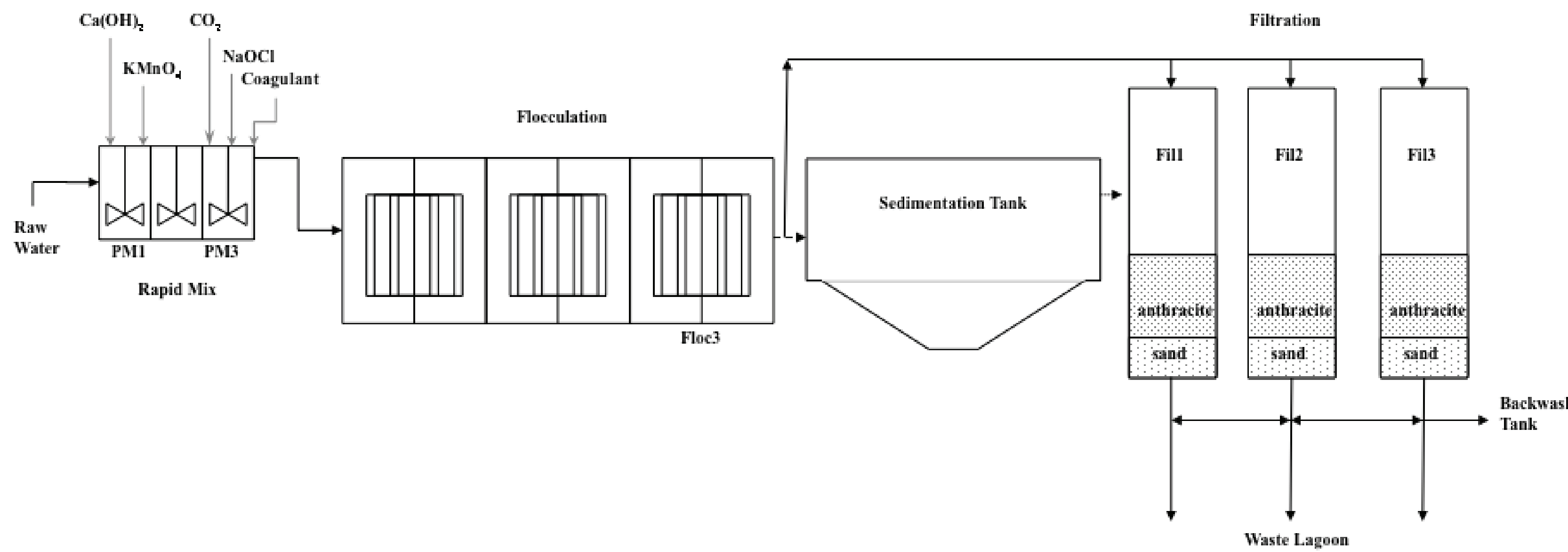


Figure 4.1 JDKWSP pilot plant treatment process schematic.

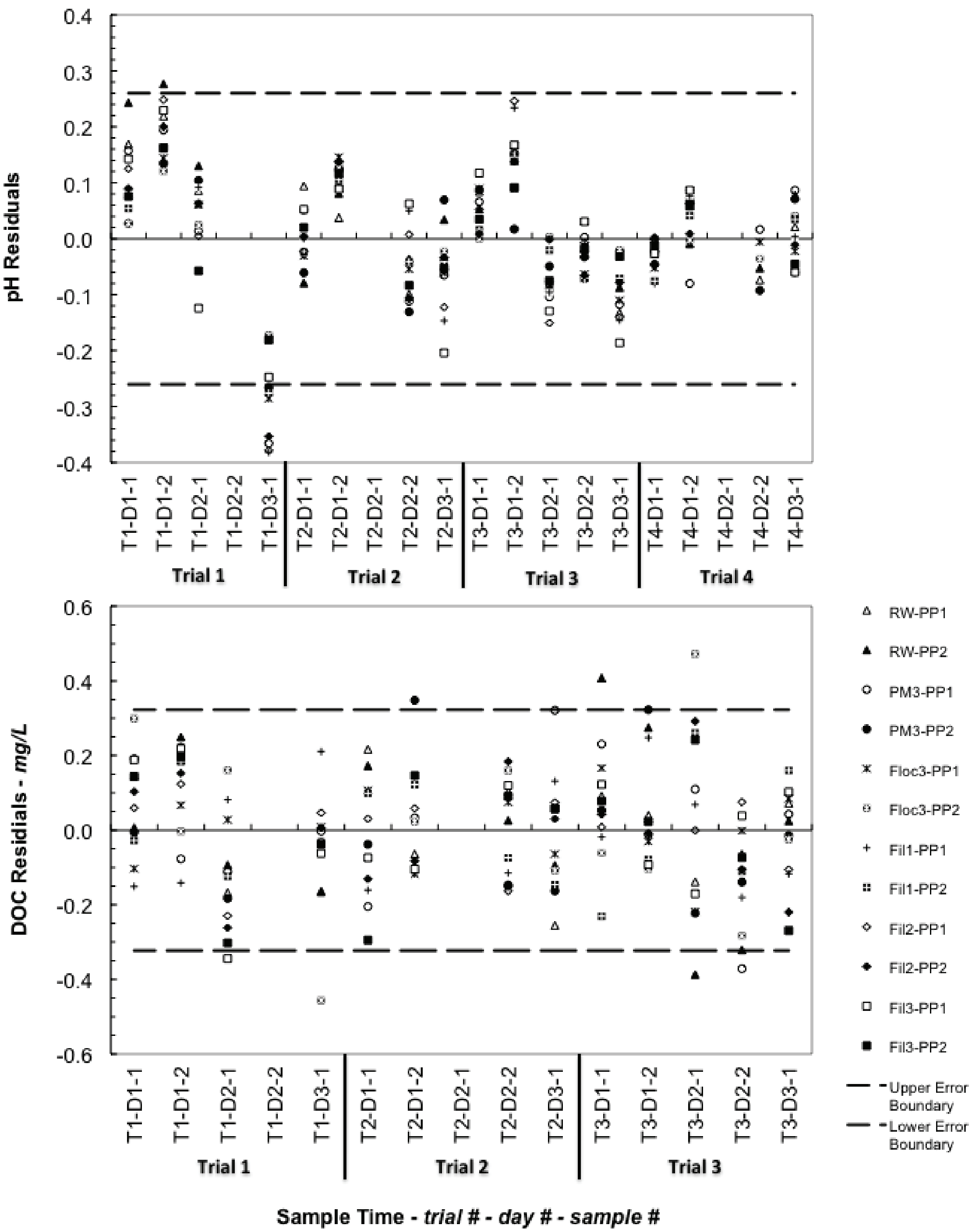


Figure 4.2 pH and DOC residuals distribution for the pilot-to-pilot proving trials completed (DOC data was not collected during trial 4). Upper and lower boundary lines represent two standard deviations of the residual population mean.

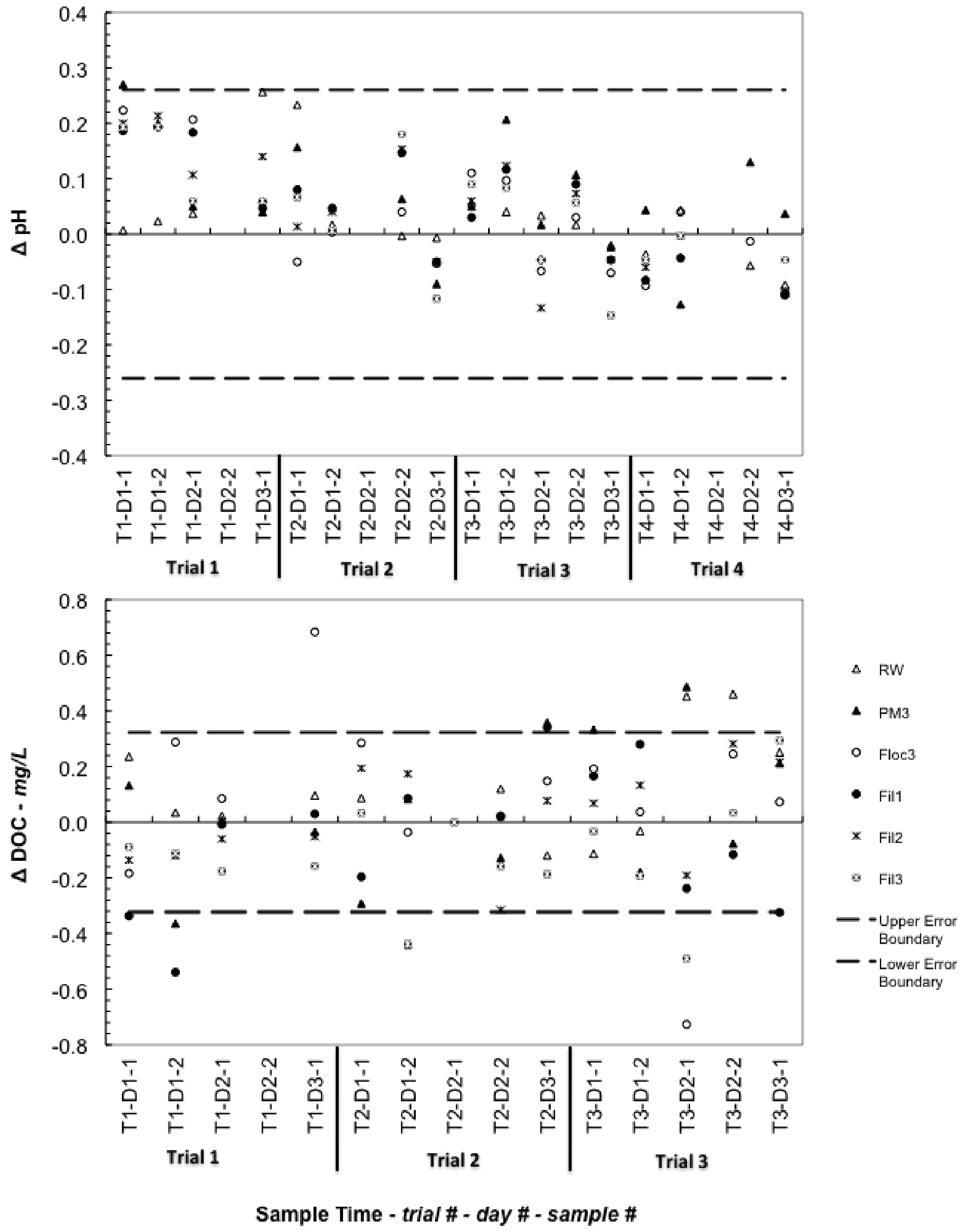
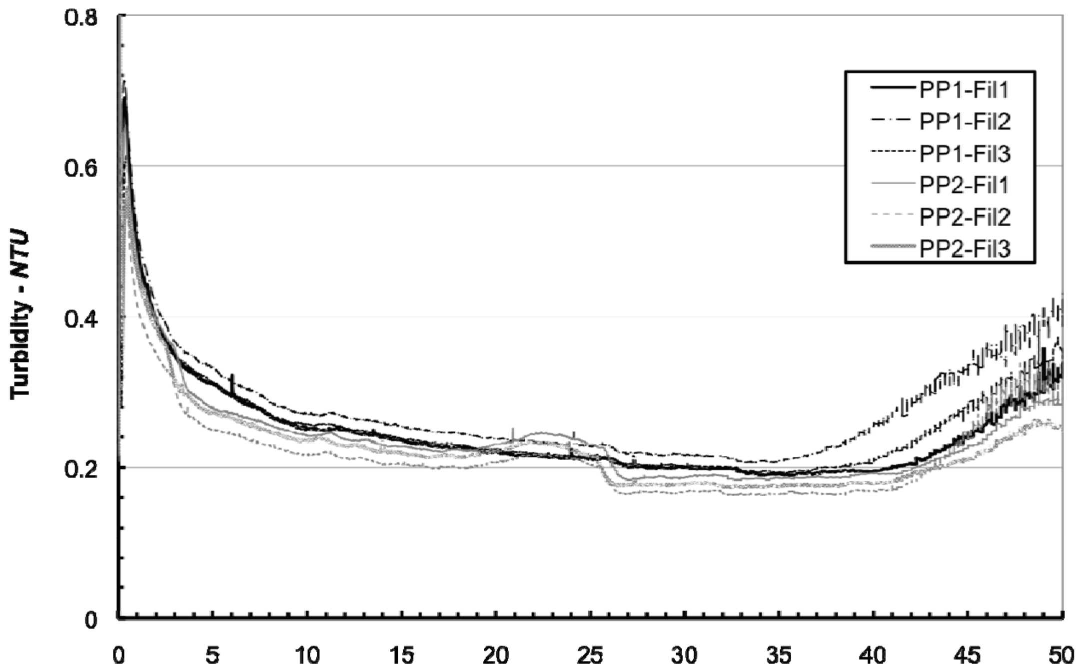


Figure 4.3 pH and DOC difference between Pilot Train 1 (PP1) and Pilot Train 2 (PP2) during pilot-to-pilot proving trials (DOC data was not collected during trial 4). Upper and lower boundary lines represent two standard deviations of the residual population mean.

a.)



b.)

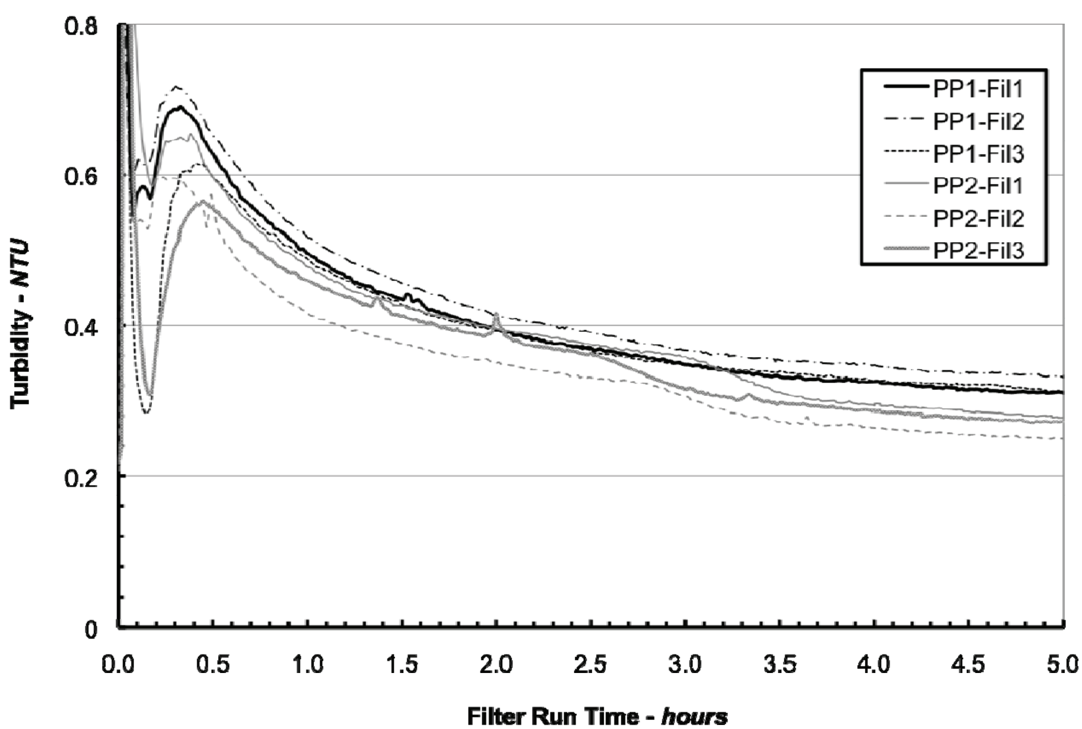


Figure 4.4 Turbidity versus filter run time (FRL) for a representative pilot-to-pilot proving trial: a) complete filter run; b) filter ripening period.

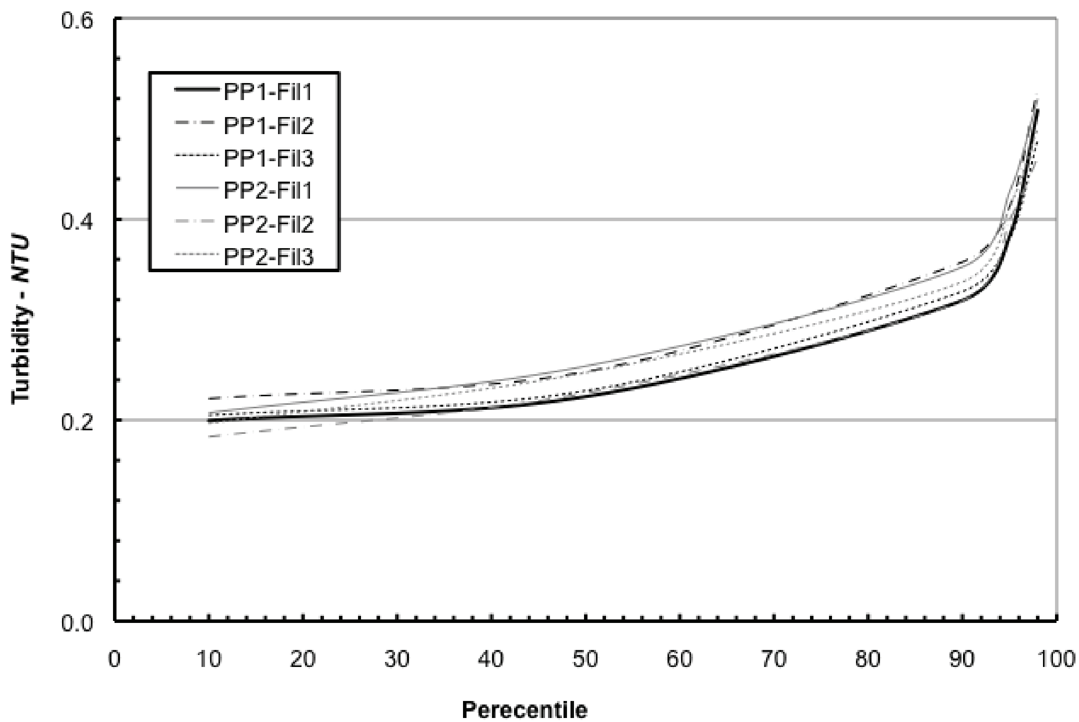
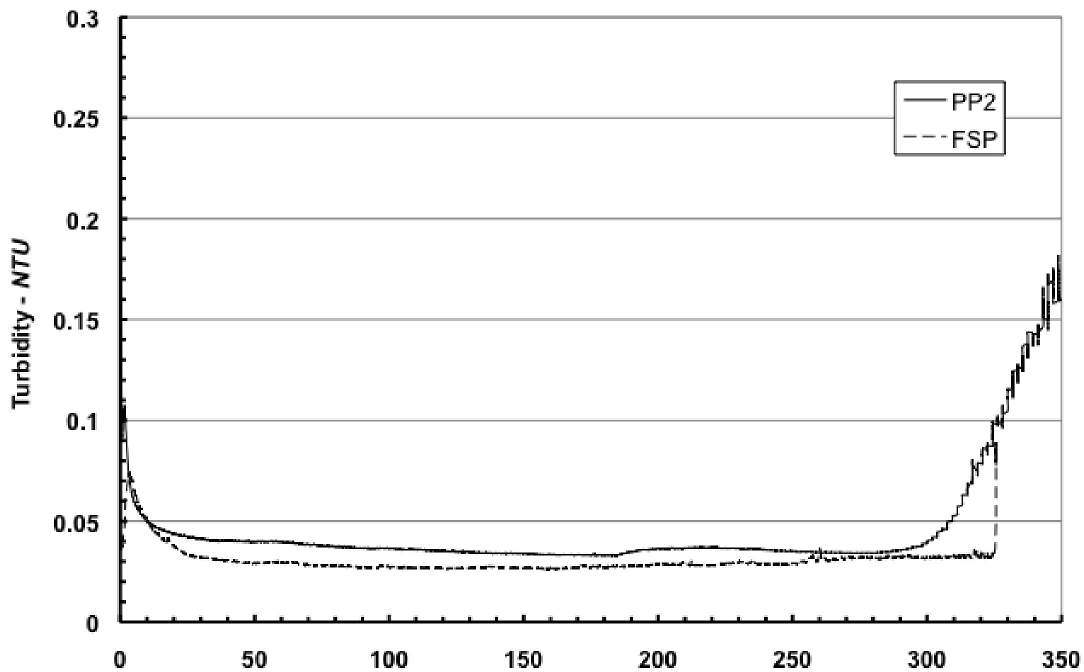


Figure 4.5 Average filtered turbidity percentile plots for each pilot filter during the four pilot-to-pilot proving trials.

a.)



b.)

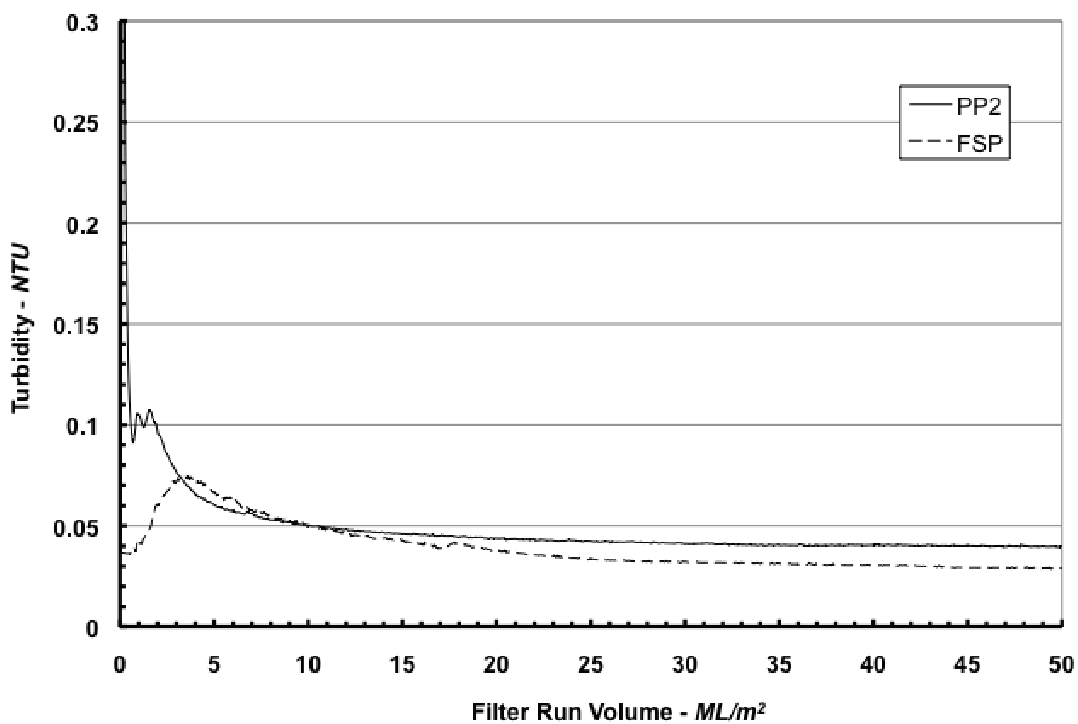


Figure 4.6 Turbidity versus unit filter run volume (UFRV) for a representative pilot-to-FSP proving trial: a) complete filter run; b) filter ripening period.

CHAPTER 5 FROM JAR-TESTING TO PILOT STUDIES: OPTIMIZING PARTICLE AND NOM REMOVAL IN A DIRECT FILTRATION WATER TREATMENT PROCESS

5.1. ABSTRACT

The goal of this research was to optimize organic matter removal during coagulation, without compromising filtration performance for the direct filtration treatment of a source water characterized by low alkalinity, low turbidity and low organic matter. Bench and pilot-scale experiments were conducted to evaluate the performance of ferric sulfate, polyaluminum chloride (PACl) and aluminum chlorohydrate (ACH) against aluminum sulfate (alum) using variable coagulant dosage and pH conditions. Results from pilot-testing demonstrated that favourable conditions identified for increased potential NOM removals during bench-scale testing were not consistent with optimal filtered water particle removal. For example the favourable ACH conditions (4.0-mg/L, pH=7.0) resulted in a 40% reduction in dissolved organic carbon (DOC) and the lowest trihalomethane formation potential (THMFP) and haloacetic acid formation potential (HAAFP) of all coagulants tested; whereas this similar dose resulted in high filtered water turbidity and low unit filter run volumes (UFRVs) when evaluated during pilot experiments. The overall results of this study show that the optimization of coagulant dosages to remove even very low organic matter concentrations can severely compromise the performance of direct filtration processes due to increased solids loading to the filters. Since coagulant overdosing is not an option, low coagulation pH was found to be the most important operating parameter during pilot-scale studies to both reduce coagulant demand and encourage the formation of soluble NOM-aluminum complexes. Finally, a useful framework was developed for interpreting and analyzing the results of various operating conditions and multi-factor response parameters generated during plant optimization studies, using performance indicators (PIs) and graphical heat-mapping techniques.

5.2. INTRODUCTION

Over the past decade, the objectives for coagulation based drinking water treatment processes have changed significantly as a result of stringent goals related to natural organic matter (NOM) removal to mitigate subsequent disinfection by-product (DBP) formation potential and the need to achieve adequate filtration performance to ensure adequate particle removal for pathogen control. Balancing NOM and particle removal objectives for the optimization of coagulation processes followed by direct filtration treatment presents significant challenges in source waters characterized by low turbidity, low alkalinity and low organic matter content.

Optimal conditions for turbidity removal are rarely the same as those for NOM removal; in fact, the coagulant demand is usually governed by the concentration of NOM for low turbidity waters (Gregor et al., 1997; Pernitsky and Edzwald, 2006). The charge of NOM in surface waters is generally more negative than that of particulate matter and, in turn, is associated with much higher coagulant demands for effective removal (Pernitsky and Edzwald, 2006). Dosing to meet NOM removal goals in a direct filtration plant leads to high solids loading to the filters and results in early breakthrough, increased head loss rates and, therefore, shorter filter run times (Eikebrokk et al., 2007). In a direct filtration process, coagulation optimization is the primary means of ensuring optimal filtration performance is achieved and the stringent filtration goals of today's regulatory regime are achieved. In addition, the removal of soluble NOM from low-level turbidity source water presents another practical challenge related to the low concentrations of stable particles available to form acceptable floc (Gregor et al., 1997; Eikebrokk et al., 2007). In direct filtration facilities, coagulation processes must be optimized with multiple performance objectives in mind.

Due to the increased challenges associated with direct filtration facilities, coagulation and flocculation processes in these types of plants are critical for achieving optimal removal of NOM and, subsequently, the mitigation of DBPs. Optimal NOM removal conditions are usually determined through the evaluation of NOM surrogate parameters such as total organic carbon (TOC), dissolved organic carbon (DOC) and UV response at 254 nm (UV_{254}) and specific UV absorbance (SUVA). The characterization of NOM to determine optimal coagulation conditions is only recently gathering attention. A number of researchers have reported that specific physical and chemical properties of NOM, including the molecular weight (MW) of organic constituents, all impact the removal of NOM during coagulation (Croue et al., 2000; Liang and Singer, 2003; Ates et al., 2007).

Since the organic composition of source waters is site specific, knowledge of the physical and chemical properties of NOM can help to optimize organic matter removal efficiencies for coagulation efforts. Organic matter is often described in terms of hydrophobic and hydrophilic fractions and there is conflicting literature regarding which NOM types are predominant as precursors of the two regulated classes of DBPs, trihalomethanes (THMs) and haloacetic acids (HAAs) (Croue et al., 2000; Liang and Singer, 2003; Ates et al., 2007). Identifying the main DBP precursors in a source water assists in the selection of optimal coagulants and coagulation operating conditions to target their removal.

Direct filtration treatment of these specific source water characteristics not only present significant challenges when optimizing current facilities to meet more stringent regulations, but these filtration processes are very difficult to simulate during bench-scale experiments. Therefore, pilot-plant experiments are essential in closing the gap between bench-scale to full-scale coagulation optimization studies in direct filtration facilities. A key advantage of a pilot plant is its ability to study these multi-objective issues simultaneously and confirm the effects of variables acting independently and in combination throughout the treatment processes.

Objectives. The goal of this research was to optimize NOM removal during coagulation, without compromising filtration performance for the direct filtration treatment of a source water characterized by low alkalinity, low turbidity and low organic matter. Bench and pilot-scale experiments were conducted to evaluate the performance of ferric sulfate, polyaluminum chloride (PACl) and aluminum chlorohydrate (ACH) against aluminum sulfate (alum) using variable coagulant dosage and pH conditions. The bench-scale study included a series of parallel jar test studies to identity favorable coagulation dosage and pH conditions for organic matter removal for each of the coagulants being considered. The pilot-scale work aimed to provide a snapshot of feasibility in terms of filter run times, filter ripening times and particle removal for favourable coagulant conditions identified under bench-scale conditions and, also, to determine favourable conditions for filtration performance. In addition, this work aimed to develop a framework for organizing and evaluating the overwhelming quantity of data generated by the various operating conditions and multi-factor response parameters generated during plant optimization studies.

5.3. MATERIALS AND METHODS

Source Water. This project was conducted at the JD Kline Water Treatment Plant (JDKWSP) in Halifax, Nova Scotia, Canada. Low levels of pH, alkalinity, turbidity and organic carbon characterize the raw water. Table 5.1 outlines the source water characteristics during the pilot proving trials.

JD Kline Water Supply Plant. The JDKWSP is a direct filtration treatment plant that employs pre-screening, oxidation, pre-chlorination, coagulation, hydraulic flocculation, direct filtration and chlorination. In the first pre-mix tank, lime is added to adjust the pH (9.6-10) for oxidation of iron and manganese using potassium permanganate ($KMnO_4$) and the second pre-mix tank provides additional mixing and detention time for this oxidation process. In the third pre-mix tank, carbon dioxide (CO_2) is added to adjust the coagulation pH (5.5-6.0) and alum is added as the primary coagulant at an average dosage of 8 mg/L. During the cold weather months (November through June), a cationic polymer is required to strengthen floc and maintain turbidity performance, at an average dosage of 0.05 mg/L. Pre-chlorination occurs in the third pre-mix tank to control biofilm occurrence in the filters and is maintained at a post-filter total chlorine residual concentration of 0.05 mg/L. Next, water is delivered to four identical flocculation trains that contain three rows of parallel sets of cells (6 cells total). Tapered, hydraulic, flocculation occurs in these cells. Next, the flow is distributed between eight dual-media anthracite and sand filters. Finished water chemicals include the addition of chlorine for disinfection to maintain a total chlorine residual of 1.0 mg/L, sodium hydroxide to a finished water pH of 7.4, zinc/ortho polyphosphate for corrosion control (0.5 mg/L as PO_4) and hydrofluosilicic acid to provide fluoride addition for dental health.

Pilot Plant Description. The JDKWSP pilot-scale plant consists of two identical, parallel treatment trains, both capable of simulating direct filtration or conventional treatment processes, manufactured by Intuitech, Tnc (Salt Lake City, Utah). The pilot plant operates using Pockwock Lake raw water at a design flow rate of 15-L/min delivered to each treatment train. Each pilot train contains two treatment trains that contain coagulation, flocculation and filtration processes.

Raw water enters the coagulation/ flocculation skid into a series of three 11.3-L rapid mix tanks where chemical addition and mixing occur. The pilot plant has the capacity to feed 6 separate chemicals through peristaltic pumps to the chemical injection ports in the rapid mix tanks. From the rapid mix tanks, water flows into a series of three 189-L mechanical flocculation tanks with paddle mixers and then on to the optional sedimentation tank. The sedimentation tank is a 330-L basin with 30 adjustable plates, each with settling area of 0.1-m^2. The clarified water is collected in a settled water basin, after passing over the settling plates, and sludge can be pumped to a sampling port or to waste. If direct filtration is desired, the sedimentation tank can be bypassed and the flow is directed straight to the filtration skid.

The pilot plant was operated as a direct filtration plant for the duration of this research project. The filtration skid was built to match the bed depths and weir elevations of the full scale plant and contains a series of three 200-mm (8-inch) diameter dual-media filters containing 61-cm (2-ft) of anthracite and 30.5-cm (1-ft) of sand. There is no capability to add finished water chemicals at the pilot scale. The plant contains inline equipment to monitor pH, temperature, and turbidity at all critical process control points.

A series of pilot proving experiments were completed to validate that statistically equivalent intermittent and finished water quality was demonstrated between pilot treatment trains and the full-scale plant (FSP). The validation process successfully demonstrated that the pilot plant has the ability to reproduce full-scale behavior and that the results of the pilot research at this facility are representative of process changes that, when implemented at full scale, will successfully optimize the performance of the FSP (Chapter 4).

5.3.1. Experimental Procedures

Bench-scale Study. A bench-scale coagulation study was completed to identify the organic matter removal potentials of each alternate coagulant and to identify reasonable coagulant dosage and pH conditions to be used as a starting point for pilot-scale coagulation studies. Since the treatment process being optimized is a direct filtration process, particle removals associated with these favorable conditions could not be evaluated during bench-scale trials. Therefore, the intention of the bench-scale work was not to determine optimum pH and coagulant dose conditions for each coagulant, but instead to establish a benchmark of the potential organic matter removal performance, which will subsequently be compared against the pH and coagulation conditions required to obtain adequate particle removals as identified through pilot testing.

The determination of reasonable pH ranges for organic matter removal for each coagulant type was determined by conducting jar tests at a constant coagulant dosage with varied pH levels. The optimal pH of coagulation was chosen based on optimal pH ranges reported in literature and overall TOC, DOC and UV_{254} removals for each coagulant used. To identify favorable coagulant dosages at the selected pH, coagulant concentrations were varied in each jar while the optimum pH value was maintained. The optimal coagulant dosage was identified as the lowest dosage at which there was maximum TOC, DOC and UV_{254} removal for each coagulant used. The resulting pH and dosage conditions were chosen as favorable operating conditions for NOM removal based on the response parameters used. Table 5.2 outlines the coagulation conditions selected for each coagulant evaluated.

Once favourable conditions were identified for each coagulant type, additional jar tests were conducted to compare these conditions the current treatment plant coagulation pH and dosage conditions, herein referred to as baseline conditions, for NOM and by-product formation potential reductions. Response parameters included TOC, DOC and UV_{254}, as well as more specific and sophisticated NOM indicators such as THM formation potential (THMFP), HAA formation potential (HAAFP), and SEC.

Jar Test Procedure. Bench-scale coagulation studies were conducted using a modified jar-test method for direct filtration with variable pH and dosage conditions. Response parameters for the bench-scale experiments focused only on NOM removal, since settled water turbidities are not relevant to direct filtration processes and deep bed filtration of direct filtration processes is difficult to adequately reproduce at the bench-scale (Pernitsky et al., 2011).

Pre-oxidized water from the full-scale treatment process was used for jar test experiments. pH was adjusted using nitric acid and sodium hydroxide. Chemicals were injected using graduated syringes and rapid mixed at 142 rpm for 1-min. Rapid mixing was followed by tapered flocculation that employed slow mixing for 12.5 minutes at 37 rpm, 12.5 minutes at 26 rpm and 12.5 minutes at 18 rpm to simulate pilot-plant operating conditions. Mixing velocities were calculated to produce equivalent mixing intensity and retention time products (GT) as the pilot treatment process (Chapter 4).

Flocculated water was then immediately filtered through a glass microfiber 1.5-µm filter (Whatman 934-AH) to imitate the direct filtration treatment stage. Filter paper was chosen instead of using small-scale filter columns in both the interest of experimental time and because preliminary testing indicated that the effluent quality based on turbidity removal was very similar when FSP coagulated/flocculated water was passed through either the 1.5-µm filter papers or small scale filtration columns. Filtered samples were analyzed for TOC, DOC and UV_{254}.

Pilot-plant Trials. Two identical treatment trains were used in the pilot study to ensure that the effects of changing raw water characteristics were eliminated by continuously operating one side of the plant such that the same finished water quality as the full-scale plant (FSP) was continuously achieved. This provided a control measurement and was used to evaluate the success of the operational parameters being evaluated. Therefore, the operating conditions of the control pilot train (e.g., chemical dosages, mixing speeds, retention times) emulated the conditions identified during the pilot proving trials outlined in Chapter 4. As outlined in Chapter 4, since the pilot plant utilizes mechanical mixers, low G-values of 30, 20, and 10-s^{-1} were chosen to emulate, to the extent possible, the inadequate hydraulic mixing intensities of the FSP. The experimental pilot train was operated under identical treatment conditions as the control train, except the coagulation pH and dosage were varied to identify optimal filtration performance coagulation conditions.

Numerous pilot-trials were conducted to evaluate the filter performance for each coagulant under various pH and dosage conditions. The trials began with a backwash of each pilot filter and were terminated based on predetermined limits including a filter effluent turbidity threshold of 0.2-NTU, a head loss limit of 2.15-m or a maximum filter run time of 80-h. In-line turbidity data for effluent filtered water was monitored continuously.

Coagulants Evaluated. The coagulants evaluated include alum, ferric sulfate, PACl and ACH. The PACl was a medium basicity coagulant containing no sulfate (MBNS) and the

ACH was a high basicity, non-sulfated (HBNS) product. The alum was supplied by General Chemical and the MBNS PACl (basicity = 40%) and HBNS ACH (basicity = 80%) were supplied by Kiemera Water Solutions Inc. To directly compare coagulant dosages, chemical dosages are report as mg/L of Al or mg/L of Fe.

5.3.2. Analytical Procedures

General Water Quality Parameters. Throughout the duration of this research, reverse osmosis (RO) water was used for all cleaning and chemical stock preparations. All glassware was rinsed 3 times using RO water following cleaning. The RO water was obtained from a Milli-Q® purification system. Combination pH/ mV/ Temperature/ DO/ ISE and Conductivity meters (Accumet* XL 25 and XL 60 models) with plastic bodied, gel-filled, combination pH electrodes (Accumet Accu-Cap*) were used for pH readings. Three-point calibration (pH 4, 7, 10) was conducted each day.

Organic Matter. TOC and DOC samples were collected head-space free in 40-mL pre-cleaned glass vials and preserved with concentrated phosphoric acid to a pH <2 and measurements were performed using a TOC-V CPH analyzer with a Shimadzu ASI-V autosampler and catalytically aided combustion oxidation non-dispersive infrared detector (NDIR) having a method detection limit of 0.08 mg/L (Shimadzu Corporation, Kyoto, Japan). UV absorbance at 254-nm (UV_{254}) was measured using a HACH DR/4000 UV/VIS spectrophotometer (Hach Company, Loveland, CO). Before sample collection, UV_{254} and DOC samples were filtered through 0.45-µm polsulfone filter membrane (GE Water & Process Technologies) that had been pre-rinsed with 500-mL of RO water.

Disinfection by-products. THMFP and HAAFP were analyzed using Standard Method 5710 (APHA, 2005) with minor modifications. Samples were buffered to a pH of 8 with borate and incubated for 24 hours following chlorination. Samples were dosed with 1.0-mg/L of buffered free chlorine to simulate current JDKWSP dosing conditions. THM and HAA samples were then prepared for gas chromatography analysis using liquid-liquid extraction (LLE) with pentane and methyl *tert*-butyl ether (MTBE), correspondingly. Gas chromatography using a Varian CP-3800 GC equipped with a VF-5 column and a Varian CP-8400 auto-sampler, coupled with an electron capture detector (GC-ECD) were used for the detection of THMs and HAAs according to the US EPA Methods 551.1 and 552.2. Samples were analyzed for four THM compounds: chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform. Samples were analyzed for 9 haloacetic acids (HAA_9): monochloroacetic acid (MCAA), monobromoacetic acid (MBAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), bromochloroacetic acid (BCAA), dibromoacetic acid (DBAA), bromodichloroacetic acid (BDCAA), chlorodibromoacetic acid (CDBAA) and tribromoacetic acid (TBAA).

To validate the precision and accuracy of the THM and HAA methods, method blanks (milli-q water) and quality control (QC) samples (milli-q spiked with a known amount of standard mixture) were prepared for every 15 samples, for any given analysis. Recovery testing was conducted on QC samples and results were only accepted if QC recoveries were between 70 and 130%. A coefficient of determination (R^2) greater than 0.95 was consistently achieved for all THM and HAA analytes.

HPSEC analysis. Molecular size distribution of organic fractions was determined by high pressure size exclusion chromatography (HPSEC) using high performance liquid chromatography (HPLC, Perkin Elmer Series 200). Prior to analysis, samples were brought to a pH of 3-7 and passed through a 0.45 μm filter membrane. Samples were evaluated using a TSK G3000SW column (7.5 mm X 300 mm) with a TSKgel SW guard column (7.5 mm X 70 mm). The media in the TSK column consists of silica, pore size of 10 μm. These columns were connected to the Perkin Elmer Series 200 Autosampler and a UV/Vis detector set at UV 254 nm. Samples of 20 μl were injected and passed through the columns at a flow rate of 0.7 mL/min. A sample run time of 30 min was established, whereby all of the compounds in the sample had passed through the column. The molecular size calibration for the column was conducted using sodium polystyrene sulfonate standards (Scientific Polymer Products Inc) with different MWs: 14900, 7540, 5180 and 1530 Daltons (Da). A coefficient of determination (R^2) greater than 0.90 was consistently achieved.

Turbidity. The pilot plant contains inline Hach 1720E low range process turbidimeters to monitor filtered water turbidity, located on the effluent stream of each individual filter on both pilot trains. When comparing filter run data between pilot trials and the FSP, in-line effluent turbidity data was extracted from HW's online monitoring system which were measured using Hach 1720 series low range process turbidimeters.

5.4. RESULTS AND DISCUSSION

5.4.1. Bench-scale Results

Organic Matter Removal. DOC concentrations in the raw water are typically low, between 2 to 3-mg/L, and specific UV absorbance (SUVA) values range from 2 to 4-m^{-1} of absorbance per mg/L of DOC (Table 5.1). SUVA values are widely used as a predictor of the aromatic organic carbon content of NOM (Croue et al., 2000, Liang and Singer., 2003; Pernitsky and Edzwald, 2006). SUVA guidelines published by Edzwald and Van Benschoten (1990) reference the nature of organic compounds and expected TOC removals associated with specific SUVA ranges (Pernitsky and Edzwald, 2006). According to these guidelines, SUVA values between 2 to 4-m^{-1} of absorbance per mg/L of DOC are indicative of an organic matrix that is composed of a combination of aquatic humics and other NOM, a mixture of both hydrophobic and hydrophilic NOM fractions, and a variety of MW organic compounds. NOM characterization studies completed on this source water determined the raw water organic matrix to be primarily comprised of hydrophobic and hydrophilic neutral compounds and the MWs of the organics species ranged from 65 to 1,000-Da (Montreuil, 2011). For SUVA values of 2 to 4, it has be suggested that the NOM present will require a greater coagulant demand than the particles present in the water and reasonable DOC removals (30 - 40%) could be expected following coagulation (Pernitsky and Edzwald, 2006).

Again, the bench-scale coagulation study was not intended to identify the optimum pH and coagulation conditions for each coagulant, but instead to establish benchmark coagulation conditions that yield favourable organic matter removal potential to minimize experimental trials during subsequent pilot studies. TOC, DOC and UV_{254} results for the favourable pH and dosage determination trials are presented Appendix B, Figures B1 through B8. The favourable pH conditions determined through a series of jar tests are presented in Table 5.2 for each coagulant studied. In general, the coagulation pH results agreed well with coagulation pH ranges reported in the literature (Pernitsky and Edzwald, 2003; Edzwald, 2008).

According to Pernitsky (2010), optimal coagulation performance for aluminum-based coagulants is typically seen at pH values close to the pH of minimum solubility where dissolved aluminum residuals are minimized and the presence of aluminum hydroxide precipitates for subsequent NOM adsorption is maximized. In contrast, ferric-based coagulants are more effective at very low pH values, where positively charged species are present and the overall negative charge of NOM is lower (Pernitsky, 2010). Volk et al. (2000) reported that several researchers identified optimal precipitation pH ranges of 4-5 with ferric-based coagulants and at 5-6 with alum. For alum, low pH values (pH = 5.5) maximize organic matter removal, whereas these low pH conditions are not required for PACls (Pernitsky, 2010). Furthermore, Pernitsky and Edzwald (2006) noted optimal PACl and ACH performance at coagulation pH values between 6-7. Favourable coagulation pH ranges increased as the basicity of the coagulant increased, as expected based on recent coagulant solubility research (Pernitsky and Edzwald, 2003; Pernitsky and Edzwald, 2006).

Since high pre-oxidation pH is required before coagulation occurs, a higher coagulation pH would significantly reduce the pH adjusting chemicals at this facility. Pernisky and Edzwald (2006) found that the use of a high basicity, non-sulfate (HBNS) PACl blend was the most effective for the removal of particles and organic matter for the direct filtration of a low alkalinity source water with low to moderate total organic matter content. This success was based on the low alkalinity consumption of high basicity PACl and the use of a high pH of coagulation due to a high minimum solubility pH associated with the high basicity PACls. In addition, PACl coagulants are generally more effective than alum in cold-water conditions, a notorious challenging treatment period at this facility, because they are pre-hydrolyzed (Pernitsky and Edzwald, 2003; Pernitsky and Edzwald, 2006). The absence of sulfate in PACl blends reduced headloss during direct filtration processes when compared directly with a sulfated PACl (Pernitsky and Edzwald, 2006).

As expected, dosage requirements increased as the coagulation pH increased for aluminum-based coagulants as shown in Table 5.2 (Pernitsky and Edzwald, 2006). At higher pHs, the coagulant demand required to react with NOM and form floc particles with a charge near neutral is increased. The coagulant dosages for PACl and ACH corresponded well with the dosage demands reported by Pernitsky and Edzwald (2006) at similar pH conditions for a low turbidity, low TOC and low alkalinity source water.

NOM of the coagulated water was predominantly in a dissolved form (Table 5.1). Therefore DOC was the primary metric of organic carbon (rather than TOC) considered when measuring coagulation performance. When compared to raw water DOC levels, reductions under baseline alum coagulation conditions yielded 20% removal of DOC and reductions from optimized coagulation conditions yielded 30–40% removals (Figure 5.1). Low DOC removals (30%) were also observed by other researchers when treating low SUVA (<3-m^{-1} of absorbance per mg/L of DOC) source waters using coagulation processes (Croue et al., 2000).

DOC removal was accompanied by a reduction in UV_{254}, which is a known surrogate for aromatic compounds such as humic substances (Figure 5.1). UV_{254} reductions were 60-70% of raw water levels, which indicates that coagulation was more effective in removing UV-absorbing, aromatic organic fractions (Croue et al., 2000). When average removals are considered, ACH had the greatest DOC and UV_{254} reductions of 40% and 70%, respectively. However, the overall DOC and UV_{254} reductions are not indicative of significant performance differences between the coagulants evaluated (Figure 5.1).

The proportion of aromatic material in treated water samples was assessed by calculating the SUVA value. The raw water SUVA was reduced from 2.6 to approximately 1.5 following coagulation treatment (Figure 5.1). SUVA interpretation guidelines indicate that the remaining NOM is hydrophilic and non-humic in nature, low in MW and only slightly affected by coagulation (Pernitsky and Edzwald, 2006; Ates et al., 2007). Organic matter characterization of FSP treated water by Montreuil (2011) indicated that coagulation efforts primarily removed the hydrophobic acid and the hydrophilic neutral fractions with little to no removal of other fractions. In addition, zeta potential analysis completed on individual organic fractions in this raw source water suggest that the net colloidal anionic charge in the raw water is driven by the zeta potential contribution of hydrophobic fractions as opposed to the hydrophilic fractions (Montreuil, 2011).

THMFP and HAAFP. DBP formation potential (DBPFP) analysis revealed further indication that the high basicity ACH was the superior performer at the coagulation conditions studied (Figures 5.2 and 5.3). ACH achieved the lowest THMFP with a 37% reduction compared to baseline coagulation conditions. On an average concentration basis, ACH achieved the greatest HAAFP reductions with a 25% decrease from baseline coagulation conditions. However, HAAFP contributions were not significantly different for any of the enhanced coagulation conditions examined.

For all treatment conditions, chlorinated by-products dominated over brominated species following treatment (Figures 5.2 and 5.3). This was expected since the bromide concentration in the raw water is 0.3-mg/L and typically less than 0.05-mg/L following treatment in the FSP. Although the average concentrations varied, consistent DBP species trends existed following treatment. For all coagulation conditions evaluated, chloroform was the dominant THM species. Small concentrations of DCBM and DBCM were also present, however these fractions were nearing minimum quantification limits. The major HAA species formed following treatment was DCAA, followed by BCAA. Minor concentrations of BDCA, MCAA, and TCAA also contributed to the average HAA concentrations. All other HAA species were below quantification limits.

UV_{254} has also been demonstrated to be a good predictor of the DBPFP of treated water (Ates et al., 2007; Edzwald 2008). For all coagulation conditions tested, weak linear correlation coefficients (R^2) were obtained between treated water UV_{254} values and THMFP and HAAFP; 0.20 and 0.53, respectively (Appendix B, Figures B11-B12). Although a relatively high correlation coefficient was obtained for the UV_{254}-HAAFP relationship, there was a high variability in HAAFP concentrations at low UV_{254} values. Since UV_{254} is only representative of UV_{254}-active, aromatic species, it doesn't capture all NOM fractions that are responsible for DBPFP, particularly for THMFP in this study. These weak correlations suggest that organic structures other than aromatics also contribute to the production of DBPFP in this treated water and the effectiveness of SUVA as a DBP prediction tool is water specific (Ates et al., 2007). That being said, recent research does suggest that HAA precursors have a higher aromatic content than THM precursors and this is likely the reason for the stronger UV_{254}-HAAFP relationship in this study (Liang and Singer, 2003).

Fractionation of NOM using SEC. Treated water was analyzed using SEC to identify and compare the MW distribution of UV_{254}-active DOC following coagulation efforts. Representative elution patterns of UV_{254} response versus elution time for each treated water condition are presented in Figure 5.4. Elution peaks were numbered for fraction identification and analysis. All chromatograms contained an early peak separated from a group of eluting peaks at later retention times. Elution fractions represent MW ranges from valley to valley on the chromatogram, which were consistent between all coagulation conditions tested (Figure 5.4). Fraction 1 eluted outside of the calibration range and was therefore not included in the analysis of MW distribution (Allpike et al., 2005). In addition, previous literature suggests that even though fraction 1 appears to be representative of high MW and highly aromatic material, it is typically associated with colloidal material that may be comprised of inorganic materials following coagulation (Allpike et al., 2005). The elution times and molecular weights associated with peaks 1 through 8 for the favourable coagulation conditions as presented in Figure 5.4 are provided in Appendix B, Figure B9.

Relative comparisons of the area of UV_{254}-active DOC for each fraction were made to compare the performance of each coagulant (Figure 5.5). Although SEC analysis using UV absorbance is a useful method to determine the MW distribution of NOM, this technique does not provide a means of assessing the mass of NOM associated with specific MW ranges; rather, it provides a means of assessing relative removals of UV-active NOM fractions within identified MW ranges (Allpike et al., 2005; Ates et al., 2007).

In general, higher removal efficiencies were obtained for large aromatic MW fractions (Figure 5.5). The greatest removals were associated with aromatic fractions greater than 1,100 Da, however MW fractions in the 700-1,100 Da size range were also mildly reduced by coagulation efforts. Generally, these highly aromatic and high MW organic compounds are associated with hydrophobic NOM and have been shown to be more amenable to removal by coagulation than hydrophilic NOM (Liang and Singer, 2003; Pernitsky and Edzwald, 2006).

Consistent with other studies, coagulation efforts were not effective at removing smaller MW compounds (<700-Da), which are generally associated with hydrophilic NOM with low aromaticity (Liang and Singer, 2003; Pernitsky and Edzwald, 2006; Ates et al., 2007). Hydrophilic organics typically encompass non-aromatic, low MW colloids with a significantly lower charge density than hydrophobic organic matters and are relatively less amenable to removal by coagulation (Liang and Singer, 2003; Pernitsky and Edzwald, 2006).

DBPFP predictions based on UV_{254} content in water characterized by low SUVA and low MW NOM fractions are generally weak and recent research is highlighting the importance of hydrophilic organic fractions with low aromaticity as being important DBP precursors in low SUVA waters (Liang and Singer, 2003; Ates et al. 2007). Although hydrophobic NOM is seen to be the major DBP precursor, in waters with a low hydrophobic content, hydrophilic organic matter may also an play and important role (Liang and Singer, 2003).

5.4.2. Pilot-scale Results

Particle Removal. The filtration performance of ferric sulfate, PACl and ACH were evaluated through a series of pilot tests under variable coagulation pH and dosage conditions (Tables 5.4 through 5.6). Filter performance was evaluated through the analysis of online filter effluent turbidity data collected for each pilot train and the FSP. One complete filter run represents the time from which the filter is put into service, until it is taken offline for backwashing; therefore one filter run includes the ripening phase, steady-state filtration operation and turbidity breakthrough.

The quantity of data generated by the various operating conditions and multi-factor response parameters were initially difficult to interpret using traditional tables or charts. Therefore, a framework was developed for organizing and evaluating this information, which included both rating individual filtration trials using performance indicators (PIs) and graphical heat-mapping techniques.

Since turbidity profiles encompass an extensive data set with several variations of effluent quality trends throughout, condensing this data into one number (i.e.; an average) for effluent comparison purposes, does not give a complete representation of the data (Hargesheimer et al., 1998). Therefore, filtration trials were evaluated based on the combined performance of three response parameters: unit filter run volumes (UFRV), steady-state turbidity values and filter ripening volumes (FRV). Filter ripening was defined as the filtered water volume required to reach a turbidity value of 0.1-NTU following a filter backwash (O'Leary et al., 2003). Each response parameter was assigned a PI score of 0 to 3 based on predefined filtration performance criteria for each response parameter (Table 5.3). PIs were based on experience with FSP filtration response parameters and industry best practice operational requirements. The resulting PI for each coagulation condition was given equivalent significance when calculating the overall treatment score.

Heat-mapping provides a graphical representation of the data using the size of a data point to represent a qualitative value of a given response parameter and the coordinate location to represent the corresponding operating conditions. For consistency, the larger data points are indicative of superior performance and, for that reason, the inverse of both turbidity and filter ripening volumes were used in the corresponding heat-maps.

Since the performance rating system applies equivalent weight to each response parameter, a means of verifying that this equitable assumption was indeed suitable is required. The conditions identified as the favourable operating region based on a calculated average may not be the appropriate choice if slightly sacrificing the performance of a single response parameter could lead to significant improvements in the other two response parameters without compromising effluent water quality. Therefore, a heat-mapping approach was used to verify that the optimal regions identified through this methodology are an appropriate choice. Heat-mapping is also a useful means of illustrating favourable operating regions for each filter response parameter and offers a means of choosing between two operating conditions that resulted in a similar overall performance rating using the PI methodology.

Pilot plant filtration data and PI ratings for ferric sulfate, PACl and ACH trials are presented, respectively, in Tables 5.4, 5.5 and 5.6. For the ferric sulfate trails completed, poor overall PI ratings (<0.6) were achieved for all coagulation conditions evaluated (Table 5.4). Excellent effluent turbidity values were achieved (<0.05-NTU) at lower pH values (4.5-4.7), however filter ripening volumes were unacceptably large and unit filter run volumes were fairly small compared to typical FSP performance (FS-4 and FS-5 in Table 5.4). By viewing the PI ratings alone, it appears that lower ferric sulfate dosages in the 4.5-4.7 pH region may have produced improved filtration performance. However, an evaluation of the ferric sulfate heat-maps suggests that lower dosages produce inferior turbidity and filter ripening performance (Figure 5.6). This was attributed to the large flocs typically produced during coagulation with ferric sulfate, but was not experimentally verified. In addition, such low coagulant pH conditions would significantly increase operating costs associated with pH adjusting chemicals at a facility that requires a high pre-oxidation pH prior to coagulation.

Pilot-scale trials conducted using favourable PACl treatment conditions identified for organic matter removal during bench-scale trials severely compromised filtration performance (PACl-3 in Table 5.5). The UFRV for these operating conditions was less than 4-m^3/m^2 and the effluent filtered water turbidities were very high. The reduced filter runs times were attributed to the increased solids loading to the filters when operating under enhanced coagulation conditions. PI ratings for PACl trials were favourable at coagulation dosage of 1.0-mg/L as Al and a pH of 5.8 (PACl-19 and PACl-20 in Table 5.5). Although these coagulation conditions provided superior filtered water turbidities and filter ripening volumes, the unit filter run volume are not ideal. This is a great example of the need and value of heat-mapping. Larger unit filter run volumes are produced at the same pH, but at a lower coagulant dosage of 0.9-mg/L as Al (Figure 5.7). Although turbidities are still acceptable at these operating conditions (0.065-NTU), filter run volumes are double the upper PI limit but could be optimized or managed through other operational means (filter loading rates, backwash optimization, etc).

The favourable ACH coagulation conditions identified during bench scale studies (ACH-

7) produced high filtered water turbidity and low UFRVs when evaluated during pilot experiments (ACH-7 in Table 5.6). Again, this was attributed to the solids loading on the filters being too high for a direct filtration process. Based upon an evaluation of the overall results obtained using ACH, the coagulation conditions for superior filtration performance were similar to those of PACl. Excellent UFRVs, effluent turbidities and FRVs were achieved at a pH value of 5.8 and a dosage range of 1.1 to 1.15-mg/L as Al (ACH-30 through ACH-37 in Table 5.6). Evaluation of the ACH heat-maps confirms these coagulations conditions as optimal regions (Figure 5.8). For all the coagulants studied, ACH provided the most promising overall results based on large UVRVs, low filtered water turbidity and low FRVs.

Figure 5.9 provides representative filtered water turbidity profiles comparing favourable ACH coagulation conditions (dose = 1.1-mg/L as Al, pH = 5.8) to same day baseline alum pilot conditions (dose = 0.9 -mg/L as Al, pH = 5.5) and FSP operations (dose = 0.7-mg/L as Al, pH = 5.5, cationic polymer = 0.05-mg/L). During cold-water operations (<10ºC), the FSP traditionally supplements their process with a cationic polymer to maintain turbidity performance, without adjusting the coagulation dose or pH. Due to the efficiency of the mechanical mixers in the pilot pant, adding a polymer to the treatment process presented high particle loading to the filters and filtered water turbidities were unacceptable. Increasing the pilot alum dose and foregoing the use of a polymer in the pilot treatment process generally brought the filter effluent turbidities to within acceptable levels (Chapter 4).

Organic Matter Removal. Organic matter removal was assessed for the coagulation conditions that produced favourable ACH filtration performance (dose = 1.1-mg/L as Al, pH = 5.8) and these results were compared to organic matter removals of same day baseline alum pilot treatment conditions (dose = 0.9-mg/L as Al, pH = 5.5) and practically optimized FSP operations (dose = 0.7-mg/L as Al, pH = 5.5, cationic polymer = 0.05-mg/L).

Treated water was analyzed using SEC to identify and compare the MW distribution of UV_{254}-active DOC following coagulation efforts that yield favourable filtration performance. Elution patterns of UV_{254} response versus detention time (Figure 5.10) and relative comparisons of the of the area of UV_{254} active DOC for each fraction remaining after treatment (Figure 5.11) revealed that the removal of aromatic organic matter was not significantly different between these three treatment scenarios. Similar to bench-scale results, high removal efficiencies were obtained for large aromatic MW fractions, whereas low MW fractions were relatively unaffected by coagulation efforts.

In contrast, THMFP and HAAFP for the FSP were significantly higher than pilot-scale treated water. The lack of correlation between Figures 5.11 and 5.12 indicates that the organic structures responsible for the higher THMFP and HAAFP of treated FSP water may not be aromatic structures. This is not conclusive, however, since both scales of treatment are pre-chlorinated at the point of coagulation. The nature and concentration of the organic precursors responsible for the formation of pre-chlorination DBPs are much different than those contributing to DBPs following coagulation. The significant differences in THMFP and HAAFP between the pilot and full-scale processes does suggest that the superior mixing conditions provided in the pilot plant increased the removal efficiencies of specific organic precursors contributing to increased THMFP and HAAFP in the FSP (Vadasarukkai, 2010).

Direct comparisons cannot be made between bench-scale results and FSP and pilot-scale results because the bench-scale experiments did not include pre-chlorination prior to coagulation since filter paper would not have the same chlorine demand as deep bed filtration. However, this bench-scale data was included in this figure to highlight that although increased THMFP reductions seemed possible following bench-scale coagulation studies, these enhanced coagulation operating conditions were not feasible to obtain acceptable filtration performance in a direct filtration facility. A dosage of 4-mg/L at a pH of 7.0 was associated with superior THMFP removals during bench-scale studies, but significantly lower dosages of 1.1 to 1.15-mg/L and pH of 5.8 were required to obtain acceptable filtration results at the pilot scale.

These results agree with other studies suggesting that direct filtration coagulation dosage and pH conditions cannot be determined by simply evaluating influent NOM characteristics and treating the water based on organic matter removal objectives (Gregor et al., 1997, Budd et al., 2004; Eikebrokk et al., 2007). Due to the limited treatment barriers present in direct filtration processes coupled with the inadequate mixing conditions identified in the FSP hydraulic flocculators (Vadasarukkai, 2010), other means of organic matter optimization need to be evaluated for this facility such as the removal of pre-chlorination practices and upgrades to mechanical flocculation.

5.5. CONCLUSIONS

Although bench-scale investigations offer a great starting point to evaluate relative performance conditions for organic matter removal, pilot-scale research is vital to effectively evaluating particle removals and filtration performance for direct filtration facilities. Results from pilot-testing demonstrated that favourable conditions identified for NOM control during bench-scale testing were not consistent with optimal filtered water particle removal. The results of this paper demonstrated that, for this source water (low turbidity, low alkalinity), the optimization of coagulant dosages to remove even very low NOM concentrations can severely compromise the filtration performance of direct filtration processes.

The nature of NOM in this source water before and after coagulation was accurately predicted by SUVA interpretation guidelines developed by Edzwald and Van Benschoten (1990) (Pernitsky and Edzwald, 2006). The overall effectiveness of coagulation processes was also correctly described by these guidelines, as the maximum organic matter removals identified during bench-scale coagulation studies were low, as predicted (30-40%). These low organic matter removal potentials are typical when treating low SUVA (<3-m^{-1} of absorbance per mg/L of DOC) source waters using coagulation processes. The overall results of this study support the general understanding that high MW, aromatic organic structures are preferentially removed by coagulation processes, whereas low MW, non-aromatic structures are recalcitrant to removal by coagulation.

Although the removals of aromatic organic compounds were shown to be high for this source water, DBPFP results provided evidence that the non-aromatic structures are also important DBP precursors. While other researchers have successfully used UV_{254} as a surrogate for predicting DBPFP, the weak UV_{254}-DBPFP correlations in this study suggest that organic structures other than aromatics also contribute to the production of DBPs. This work supports recent research indicating that DBP predictions based on UV_{254} content in water characterized by low SUVA and low MW NOM fractions are generally weak and, therefore, highlights the importance of hydrophilic organic fractions with low aromaticity as being important DBP precursors in low SUVA waters.

Although bench-scale studies were indicative of a potential increase in organic matter removals using enhanced coagulation conditions, the pilot-scale studies proved that these operating conditions were not favourable when filtration performance was considered. The greatest limitation faced in removing NOM during direct filtration treatment is the high solids loading resulting from the coagulant demand required for optimal NOM removal. Since coagulant overdosing is not an option, coagulation pH becomes very important for these facilities. For low turbidity source water with low organic content, a low coagulation pH will decrease the negative charge of NOM and, therefore, reduce the amount of coagulant required for charge neutralization, and encourage the formation of soluble NOM-aluminum complexes due to the increased concentrations of highly charged metal species at lower pH values.

The coagulation conditions that were required to obtain favourable filtration performance using an alternate coagulant (ACH at 1.1-mg/L and pH = 5.8) did not provide any organic matter removal benefits when compared to the performance of the control pilot train operating using the same day baseline operating conditions (Alum at 0.9-mg/L, pH = 5.5) as the FSP plant. Although, filtration performance was improved using ACH based on shorter filter ripening time and lower filter effluent turbidities.

Significant differences were identified between the DBPFP between pilot plant treated water and FSP treated water using similar coagulation conditions. The higher DBPFP of FSP treated water demonstrate the poor mixing performance associated with hydraulic flocculators during full-scale treatment and highlighted the increased NOM removal benefits associated with mechanical mixing capabilities of the pilot plant (Vadasarukkai, 2010).

This study also provides a useful framework for analyzing the overwhelming quantity of data generated by the various operating conditions and multi-factor response parameters generated during plant optimization studies. This framework organized and evaluated this information using indicators (PIs) and graphical heat-mapping techniques. Performance indicator scores were used to assess coagulation operating conditions based on the combined performance of unit filter run volumes (UFRV), steady-state turbidity values and filter ripening volumes (FRV). The resulting performance indicator for each coagulation condition was given equivalent significance when calculating the overall treatment score. Heat-mapping techniques were successfully used to verify that this equitable assumption was indeed suitable and also to visually simplify and identify favourable operating regions for each filter response parameter.

Overall, this research highlights the overall sensitivity and difficulty associated with optimizing direct filtration coagulation processes. It also stresses the importance of investigating coagulation as a multi-objective optimization process in which both turbidity and organic removal are important output parameters. Finally, it emphasizes the need for further research of ways to reduce DBP precursors in direct filtration facilities without compromising filtration performance.

Table 5.1 Raw Water Characteristics

Analyte	Warm Water (10 to 20 - ºC) Range	Warm Water (10 to 20 - ºC) Average	Cold Water (2 to 10 - ºC) Range	Cold Water (2 to 10 - ºC) Average
Temperature - ***°C***	11.6 – 20.9	16.2	1.0 – 9.6	4.0
pH	4.9 – 5.4	5.1	4.9 – 5.3	5.0
Alkalinity – ***mg/L as*** $CaCo_3$	---	<1	---	<1
Turbidity - ***NTU***	0.28 – 0.49	0.39	0.29 – 0.46	0.37
UV_{254} **-** cm^{-1}	0.051 – 0.085	0.069	0.082 – 0.103	0.093
TOC - ***mg/L***	1.412 – 2.947	2.545	2.771 – 3.337	2.940
DOC - ***mg/L***	1.808 – 3.221	2.612	2.056 – 3.184	2.858
SUVA – m^{-1} ***per mg/L of DOC***	2.8 – 4.2	3.3	2.0 – 2.9	2.5

Table 5.2 Coagulation dose and pH conditions determined for enhanced organic matter removal during **bench-scale** trials.

	Dose (mg/L)	pH
Alum	1.3 as Al	5.5
Ferric Sulfate	1.9 as Fe	4.5
PACl	1.65 as Al	6.0
ACH	4.0 as Al	7.0

Table 5.3 Criteria for **pilot plant** filtration performance indicators (PI).

PI	UFRV - m^3/m^2	FRV[1] - m^3/m^2	Turbidity - *NTU*
0	< 90 (< 20)[2]	> 4.5 (> 1)	> 0.2
1	90 – 180 (20 – 40)	2.25 – 4.5 (0.5 – 1)	0.1 – 0.2
2	180 – 270 (40 – 60)	1.125 – 2.25 (0.25 – 1)	0.05 – 0.1
3	270 – 360 (60-80)	< 1.125 (< 0.25)	< 0.05

[1]Filter ripening volume = volume of water filtered to reach effluent turbidity <0.1-NTU.
[2]Values in parenthesis represent the equivalent filtration time (h) based on a 4,500 $L/h/m^2$ filter loading rate.

Table 5.4 Pilot plant filtration data and performance indicator (PI) ratings for ferric sulfate **pilot trials**.

Trial No.	Coagulant Dose- *mg/L as Fe*	pH	Temp. °*C*	Raw Water Turbidity - *NTU*	UFRV m^3/m^2	UFRV PI (X/3)	FRV m^3/m^2	FRV PI (X/3)	Turbidity *NTU*	Turbidity PI (X/3)	Overall (X/1)
FS-1	3.6	5	19.7	0.448	143*	**1**	5.6	**0**	0.059	**2**	***0.3***
FS-2	3.1	5.2	19.4	0.456	109	**1**	NR[1]	**0**	0.344	**0**	***0.1***
FS-3	2.9	5.2	19.4	0.388	5	**0**	NR	**0**	0.640	**0**	***0.0***
FS-4	3.1	4.5	15.3	0.355	167	**1**	4.9	**0**	0.036	**3**	***0.4***
FS-5	3.1	4.7	14.3	0.348	181	**2**	9.2	**0**	0.034	**3**	***0.6***
FS-6	3.1	5	14.3	0.391	191	**2**	8.9	**0**	0.060	**2**	***0.4***
FS-7	2.6	5	12.6	0.344	248**	**2**	128.3	**0**	0.164	**1**	***0.3***
FS-8	2.6	4.1	11.6	0.342	173	**1**	1.3	**2**	0.077	**2**	***0.6***
FS-9	2.6	4	10.4	0.39	265	**2**	29.6	**0**	0.098	**2**	***0.4***
FS-10	2.4	5.8	10.4	0.307	5	**0**	NR	**0**	1.999	**0**	***0.0***
FS-11	2.4	6	10.4	0.337	5	**0**	NR	**0**	1.999	**0**	***0.0***
FS-12	1.2	6	10.2	0.305	5**	**0**	NR	**0**	0.509	**0**	***0.0***
FS-13	1.2	5	9.6	0.337	5	**0**	NR	**0**	1.357	**0**	***0.0***
FS-14	2.4	5	9.6	0.326	285	**3**	NR	**0**	0.246	**0**	***0.3***

* Indicates filtration trials that terminated based on head loss >2.15-m. All other trials were terminated based on turbidity breakthrough (>0.2-NTU).
** Indicates trials that were terminated based on head loss and turbidity breakthrough.
[1]NR = Never Ripened (i.e., turbidities were never below 0.1-NTU)

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Table 5.5 Pilot plant filtration data and performance indicator (PI) ratings for PACl (MBNS) **pilot trials**.

Trial No.	**Coagulant Dose** *mg/L as Al*	**pH**	**Temp.** *°C*	**Raw Water Turbidity** - *NTU*	**UFRV** m^3/m^2	**UFRV PI (X/3)**	**FRV** m^3/m^2	**FRV PI (X/3)**	**Turbidity** *NTU*	**Turbidity PI (X/3)**	**Overall (X/1)**
PACl-1	1.7	6.0	5.9	0.478	81	**0**	3.4	**1**	0.032	**3**	***0.4***
PACl-2	1.7	6.2	6.4	0.468	73	**0**	2.9	**1**	0.034	**3**	***0.4***
PACl-3	1.4	6.2	6.4	0.473	4	**0**	NR[1]	**0**	>0.2[2]	**0**	***0.0***
PACl-4	1.5	5.9	6.4	0.462	50	**0**	2.3	**2**	0.035	**3**	***0.6***
PACl-5	0.8	5.8	5.0	0.484	139	**1**	58.4	**0**	0.114	**1**	***0.2***
PACl-6	0.8	5.9	6.0	0.470	0	**0**	NR	**0**	0.252	**0**	***0.0***
PACl-7	0.8	5.7	6.0	0.441	146*	**1**	NR	**0**	0.133	**0**	***0.2***
ACl-8	0.8	6.0	7.4	0.582	155	**1**	41.7	**0**	0.115	**1**	***0.2***
PACl-9	0.8	6.2	7.4	0.525	0	**0**	NR	**0**	0.412	**0**	***0.0***
PACl-10	1.1	6.0	6.9	0.603	91	**1**	15.0	**0**	0.078	**2**	***0.3***
PACl-11	1.1	5.9	8.0	0.588	95	**1**	5.3	**0**	0.057	**2**	***0.3***
PACl-12	1.1	5.8	8.0	0.566	86	**0**	3.2	**1**	0.029	**3**	***0.4***
PACl-13	1.1	5.7	8.0	0.604	85	**0**	11.7	**0**	0.029	**3**	***0.3***
PACl-14	**1.1**	**5.6**	**7.9**	**0.556**	**113**	**1**	**3.1**	**1**	**0.04**	**3**	***0.6***
PACl-15	0.8	5.9	20.6	0.325	248	**2**	5.3	**0**	0.052	**2**	***0.4***
PACl-16	1.0	5.8	20.4	0.323	188	**2**	4.5	**1**	0.035	**3**	***0.7***
PACl-17	0.9	5.8	20.7	0.315	330	**3**	8.0	**0**	0.063	**2**	***0.6***
PACl-18	0.6	5.8	21.7	0.337	0	**0**	NR	**0**	>0.2	**0**	***0.0***
PACl-19	1.0	5.8	22.1	0.305	169	**1**	1.1	**3**	0.032	**3**	***0.8***
PACl-20	1.0	5.8	22.6	0.300	227	**2**	1.7	**2**	0.041	**3**	***0.8***

* Indicates filtration trials that terminated based on head loss > 2.15-h. All other trials were terminated based on turbidity breakthrough (>0.2-NTU).
[1]NR = Never Ripened (i.e., turbidities were never below 0.1-NTU)
[2]Turbidities noted as >0.2-NTU correspond with filter run times less than 5-hrs.

Table 5.6 Pilot plant filtration data and performance indicator (PI) ratings for ACH (HBNS) **pilot trials**.

Trial No.	Coagulant Dose *mg/L as Al*	pH	Temp. *°C*	Raw Water Turbidity - *NTU*	UFRV m^3/m^2	UFRV PI (X/3)	FRV m^3/m^2	FRV PI (X/3)	Turbidity *NTU*	Turbidity PI (X/3)	Overall (X/1)
ACH-1	0.90	6.3	22.4	0.307	300*	**3**	14.9	**0**	0.076	**2**	***0.6***
ACH-2	1.50	5.6	22.5	0.373	162	**1**	2.3	**2**	0.037	**3**	***0.7***
ACH-3	1.50	6.3	22.5	0.424	53	**0**	0.8	**3**	0.138	**1**	***0.4***
ACH-4	3.00	5.6	21.1	0.446	146	**1**	28.1	**0**	0.035	**3**	***0.4***
ACH-5	1.25	5.6	17.4	0.434	119	**1**	3.6	**1**	0.068	**2**	***0.4***
ACH-6	1.25	6.3	16.1	0.420	95	**1**	2.6	**1**	0.08	**2**	***0.4***
ACH-7	4.00	7.0	11.1	0.419	30	**0**	2.2	**2**	0.288	**0**	***0.2***
ACH-8	1.20	7.0	11.3	0.411	74	**0**	NR[1]	**0**	0.139	**1**	***0.1***
ACH-9	1.00	7.0	12.0	0.411	74	**0**	NR	**0**	0.179	**1**	***0.1***
ACH-10	1.00	6.2	10.6	0.417	203	**2**	7.0	**0**	0.051	**2**	***0.4***
ACH-11	1.10	6.3	10.1	0.425	153	**1**	3.1	**1**	0.052	**2**	***0.4***
ACH-12	1.20	6.3	10.1	0.446	126	**1**	2.1	**2**	0.031	**3**	***0.7***
ACH-13	0.90	6.2	10.1	0.433	180	**1**	NR	**0**	0.373	**0**	***0.1***
ACH-14	1.40	6.3	8.2	0.444	108	**1**	3.2	**1**	0.036	**3**	***0.6***
ACH-15	1.50	6.3	8.2	0.493	90	**0**	1.8	**2**	0.039	**3**	***0.6***
ACH-16	0.90	7.0	2.6	0.394	5	**0**	NR	**0**	>0.2[2]	**0**	***0.0***
ACH-17	0.90	7.0	2.6	0.406	203	**2**	45.8	**0**	0.209	**0**	***0.2***
ACH-18	0.90	6.5	2.8	0.421	146	**1**	68.3	**0**	0.129	**1**	***0.2***
ACH-19	0.90	6.0	3.2	0.404	181	**2**	48.4	**0**	0.121	**1**	***0.3***
ACH-20	1.50	6.0	3.9	0.403	118	**1**	0.5	**3**	0.03	**3**	***0.8***
ACH-21	1.50	6.0	4.5	0.483	81	**0**	3.0	**1**	0.029	**3**	***0.4***
ACH-22	1.50	6.5	4.1	0.503	79	**0**	0.5	**3**	0.04	**3**	***0.7***
ACH-23	0.90	6.5	4.1	0.513	5	**0**	NR	**0**	>0.2	**0**	***0.0***
ACH-24	2.00	6.5	6.1	0.451	59	**0**	2.2	**2**	0.028	**3**	***0.6***
ACH-25	0.50	6.5	7.6	0.485	5	**0**	NR	**0**	>0.2	**0**	***0.0***
ACH-26	0.70	6.0	7.3	0.492	5	**0**	NR	**0**	>0.2	**0**	***0.0***

Trial No.	Coagulant Dose *mg/L as Al*	pH	Temp. *°C*	Raw Water Turbidity - *NTU*	UFRV m^3/m^2	UFRV PI (X/3)	FRV m^3/m^2	FRV PI (X/3)	Turbidity *NTU*	Turbidity PI (X/3)	Overall (X/1)
ACH-27	0.90	5.8	8.7	0.479	320	**3**	18.0	**0**	0.093	**2**	***0.6***
ACH-28	1.00	5.8	10.5	0.473	360**	**3**	6.8	**0**	0.067	**2**	***0.6***
ACH-29	1.00	5.8	11.0	0.442	360**	**3**	4.3	**1**	0.053	**2**	***0.7***
ACH-30	1.10	5.8	12.0	0.425	335	**3**	2.9	**1**	0.044	**3**	***0.8***
ACH-31	1.10	5.8	14.2	0.419	253	**2**	0.2	**3**	0.029	**3**	***0.9***
ACH-32	1.10	5.8	13.7	0.425	349	**3**	0.4	**3**	0.026	**3**	***1.0***
ACH-33	1.15	5.8	14.9	0.391	255	**2**	0.6	**3**	0.029	**3**	***0.9***
ACH-34	1.10	5.8	16.5	0.379	267	**2**	0.5	**3**	0.026	**3**	***0.9***
ACH-35	1.10	5.8	17.2	0.341	299	**3**	0.5	**3**	0.03	**3**	***1.0***
ACH-36	1.10	5.8	18.6	0.324	299	**3**	0.4	**3**	0.028	**3**	***1.0***
ACH-37	1.15	5.8	21.5	0.292	344	**3**	0.3	**3**	0.028	**3**	***1.0***

* Indicates filtration trials that terminated based on head loss >2.15-m. All other trials were terminated based on turbidity breakthrough (>0.2-NTU).
** Indicates trials that were terminated based on total filtration hours > 80-h. All other trials were terminated based on turbidity breakthrough(>0.2-NTU)
[1]NR = Never Ripened (i.e., turbidities were never below 0.1-NTU)

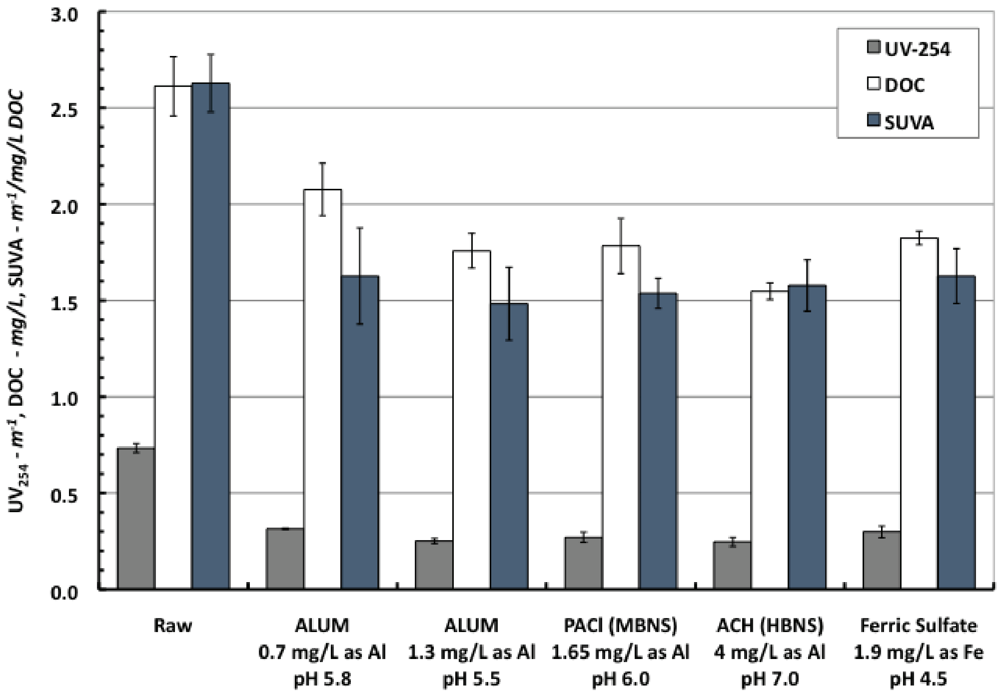


Figure 5.1 UV_{254}, DOC and SUVA results for favourable coagulation conditions identified for organic matter removal during **bench-scale** coagulation trials (± standard deviation of triplicate conditions).

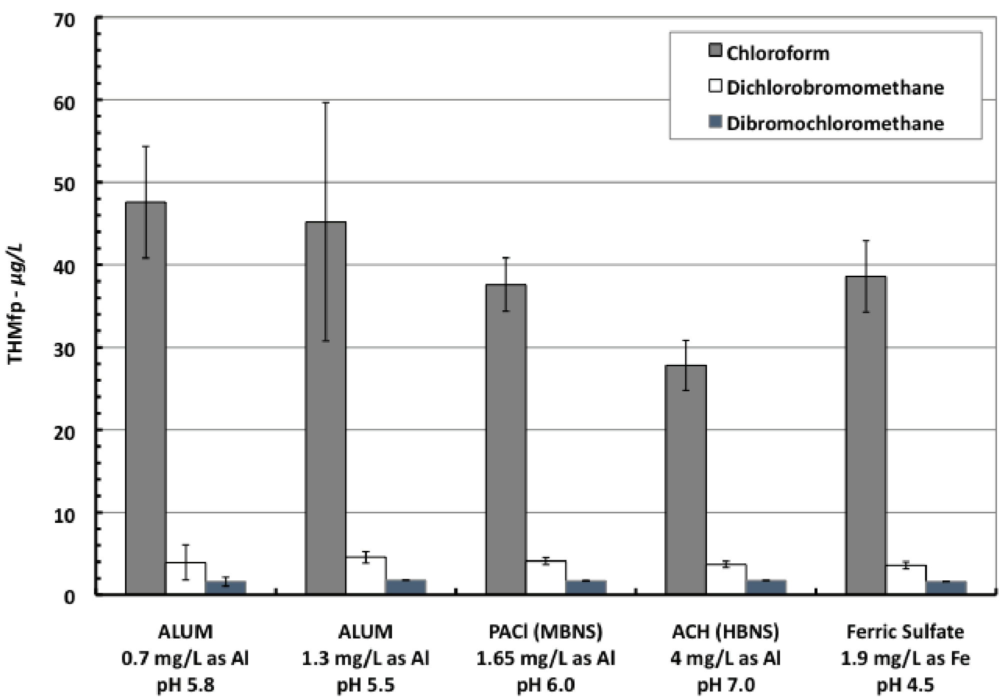


Figure 5.2 THMFP results for favourable coagulation conditions identified for organic matter removal during **bench-scale** coagulation trials (± standard deviation of triplicate conditions). Bromoform results were well below minimum quantification limits.

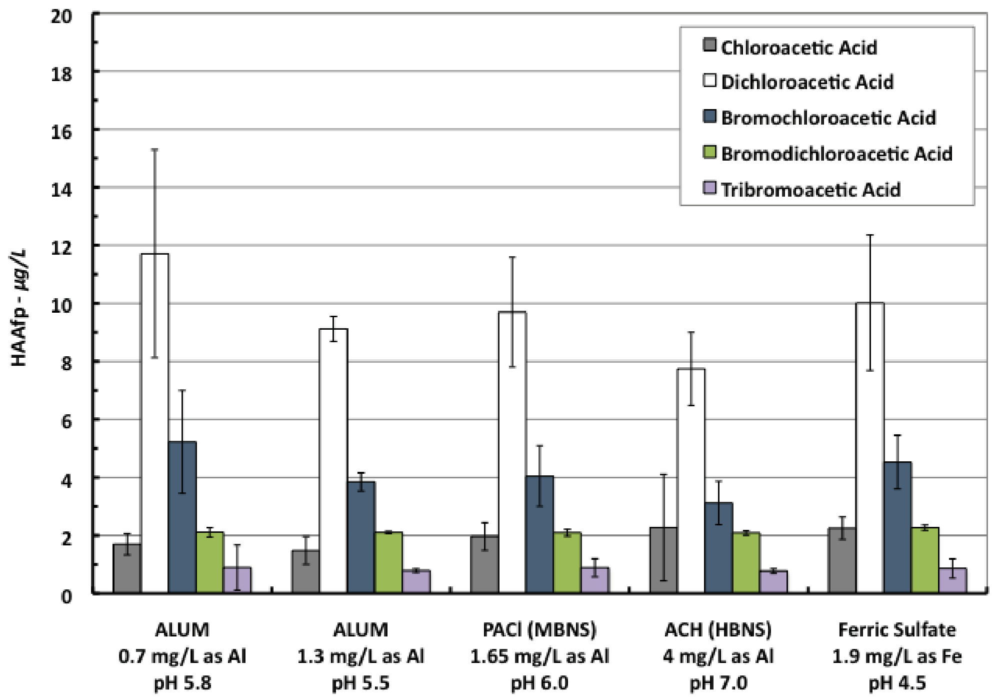


Figure 5.3 HAAFP results for favourable coagulation conditions identified for organic matter removal during **bench-scale** coagulation trials (± standard deviation of triplicate conditions). All other HAAs tested were well below minimum quantification limits.

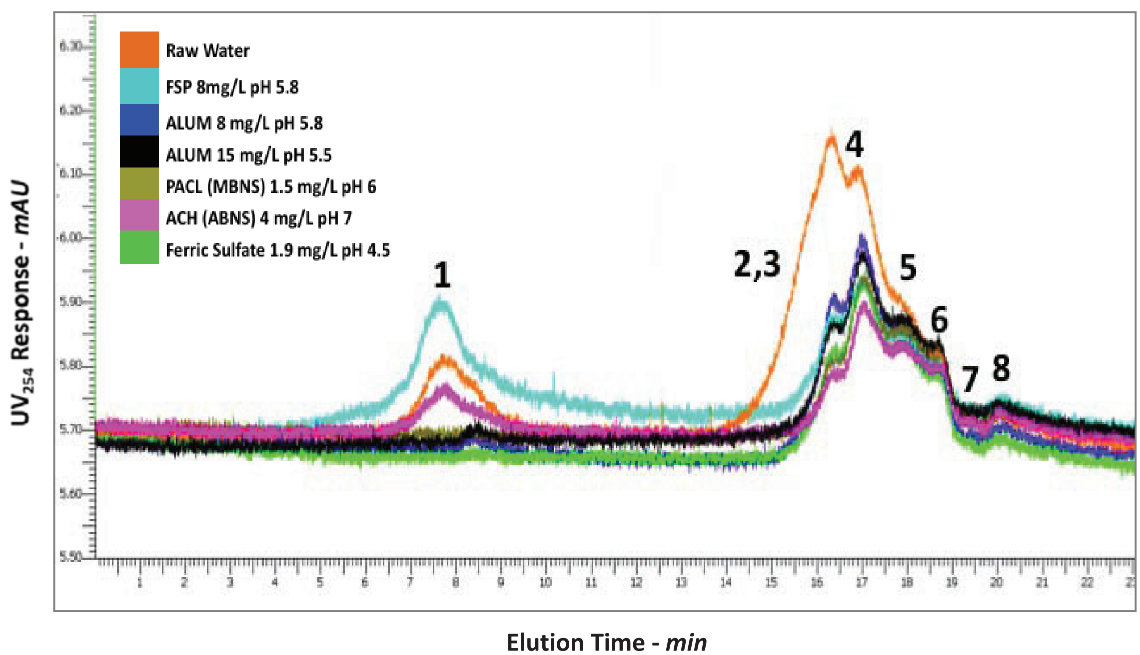


Figure 5.4 SEC chromatogram for favourable coagulation conditions identified for organic matter removal during **bench-scale** coagulation trials. Fractions in the chromatograph are numbered for AMW fraction identification.

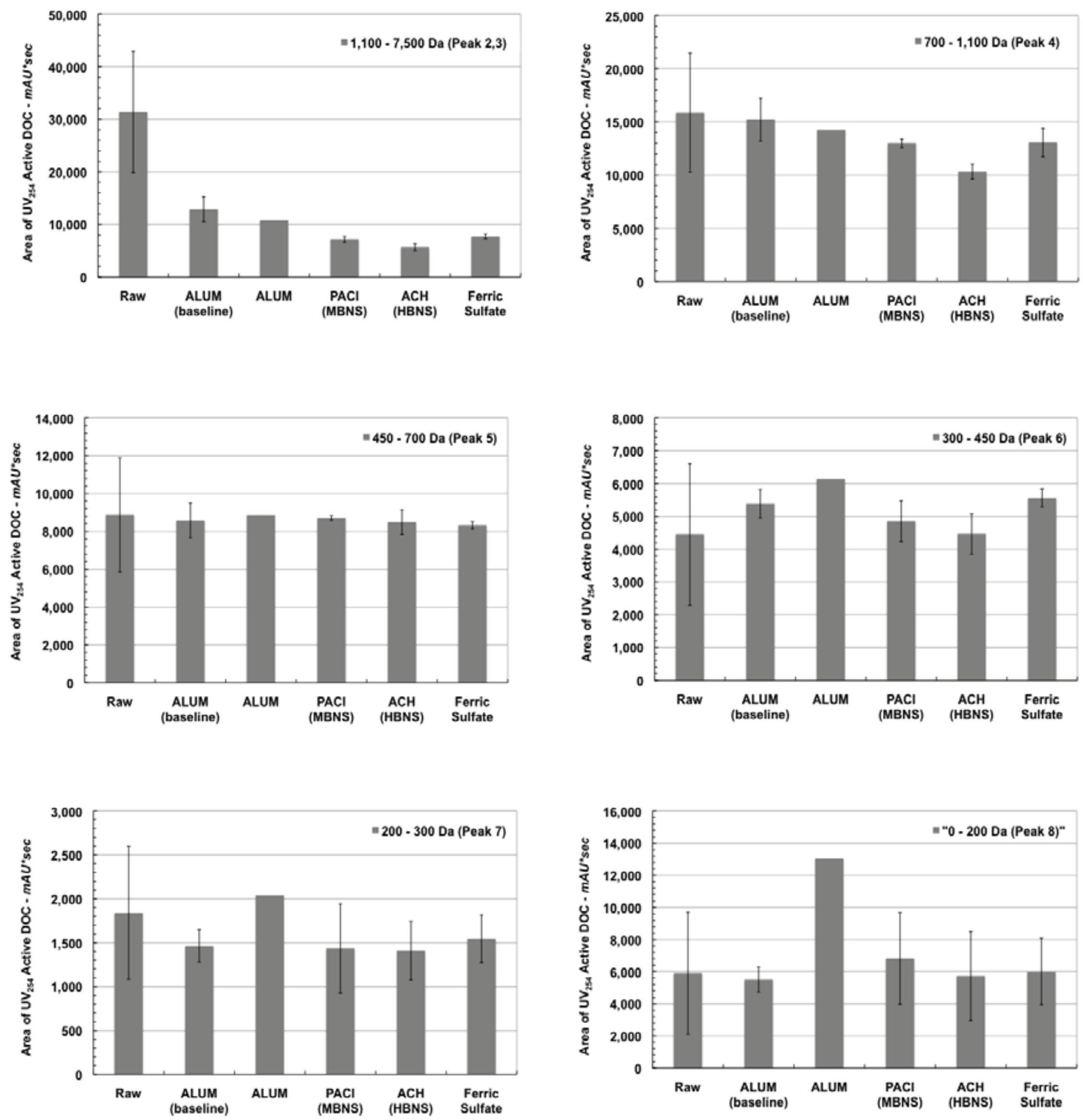


Figure 5.5 Area of UV_{254} Active DOC (mAU*sec) in different MW fractions for favourable coagulation conditions identified for organic matter removal during **bench-scale** coagulation trials.

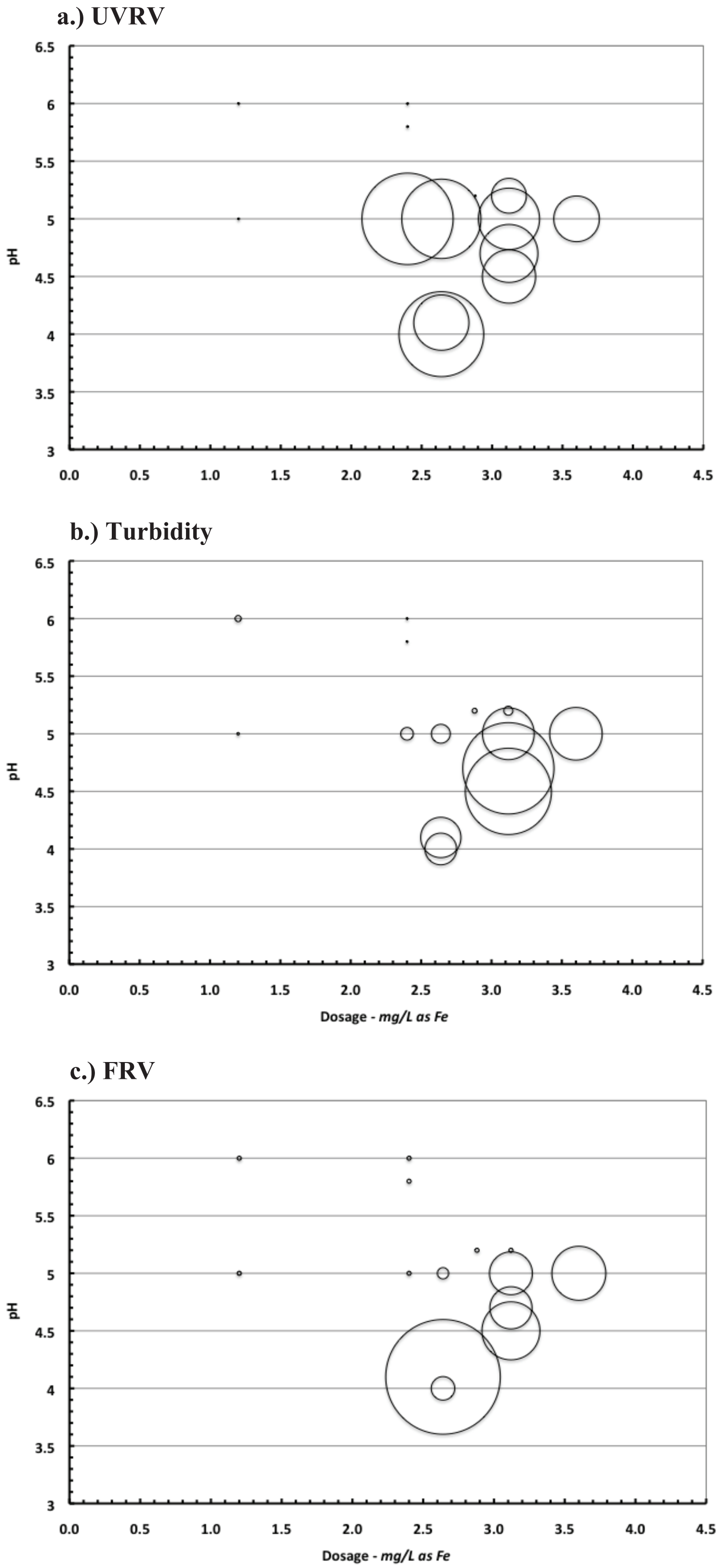


Figure 5.6 Heat maps of unit filter run volume (UFRV), inverse turbidity and inverse filter ripening volume (FRV) for ferric sulfate **pilot trials**.

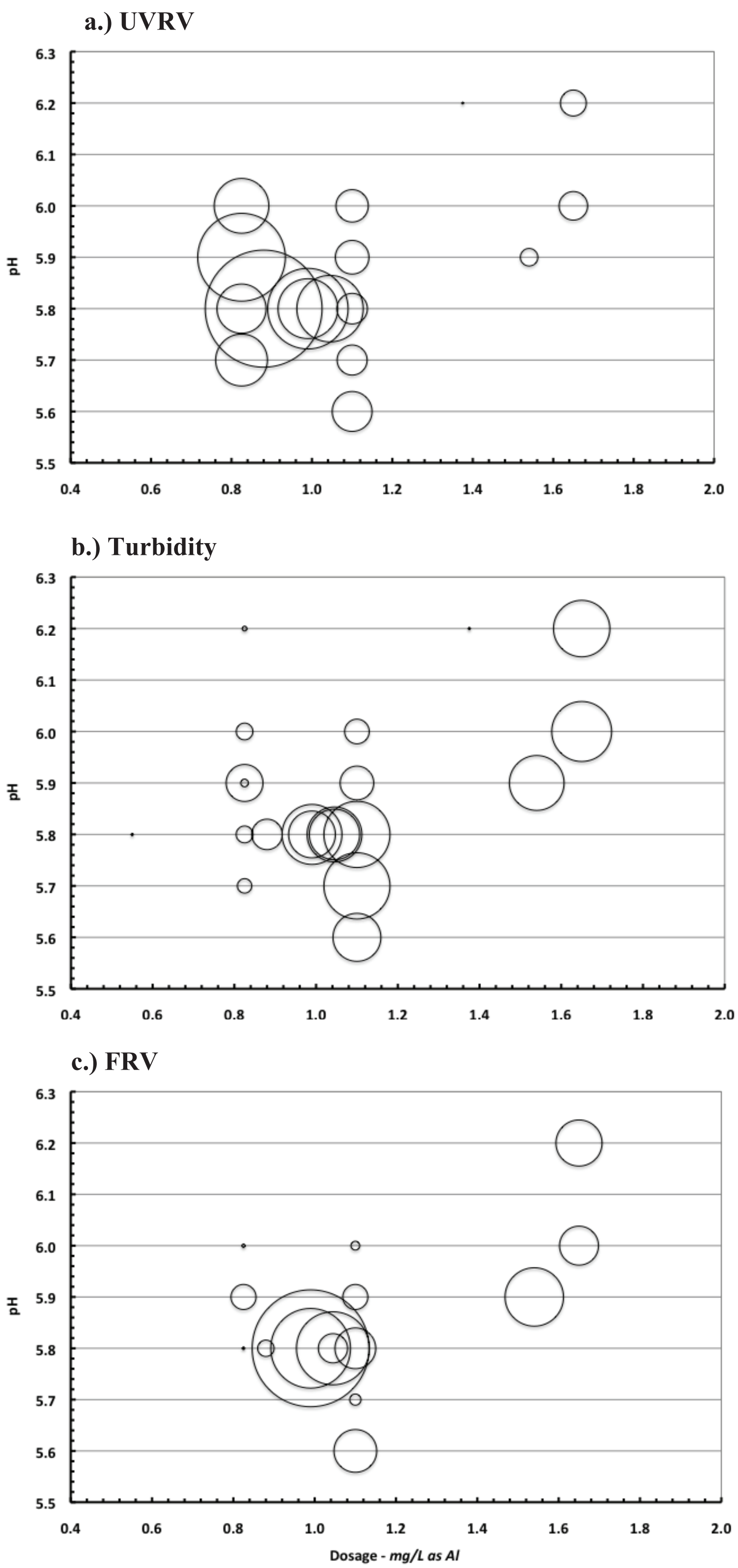


Figure 5.7 Heat maps of unit filter run volume (UFRV), inverse turbidity and inverse filter ripening volume (FRV) for PACl (MBNS) **pilot trials.**

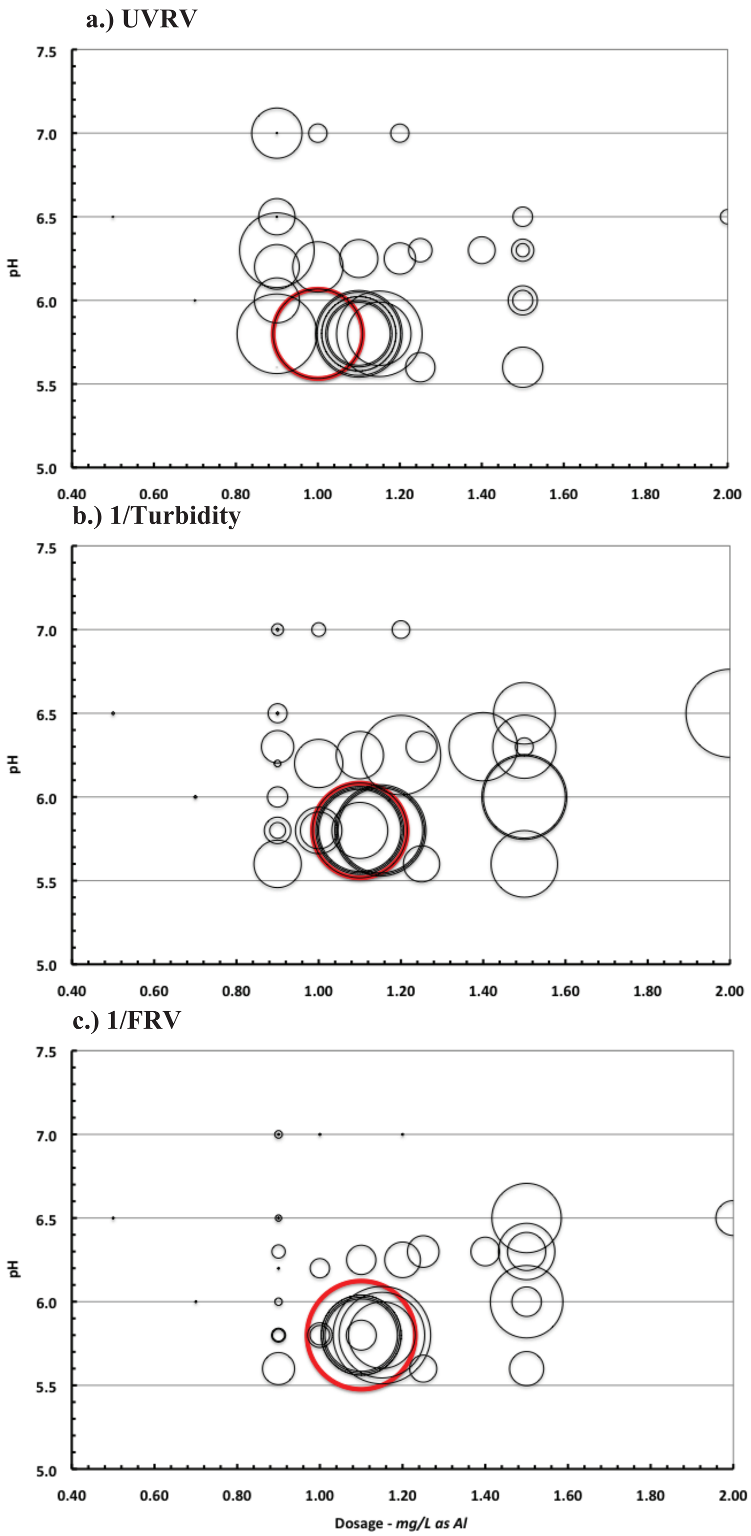


Figure 5.8 Heat maps of unit filter run volume (UFRV), inverse turbidity and inverse filter ripening volume (FRV) for ACH (HBNS) **pilot trials.** Highlighted circles indicate optimal operating conditions.

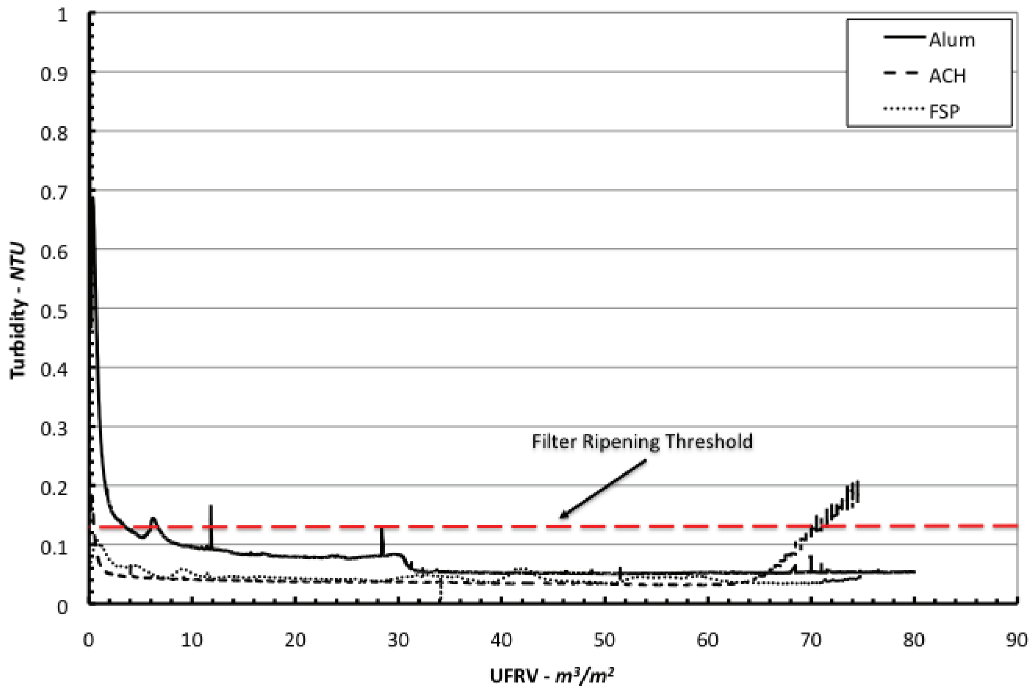


Figure 5.9 Representative **pilot-scale** filtered water turbidity profiles comparing favourable ACH (HBNS) filtration conditions to same day baseline Alum pilot conditions and FSP operations.

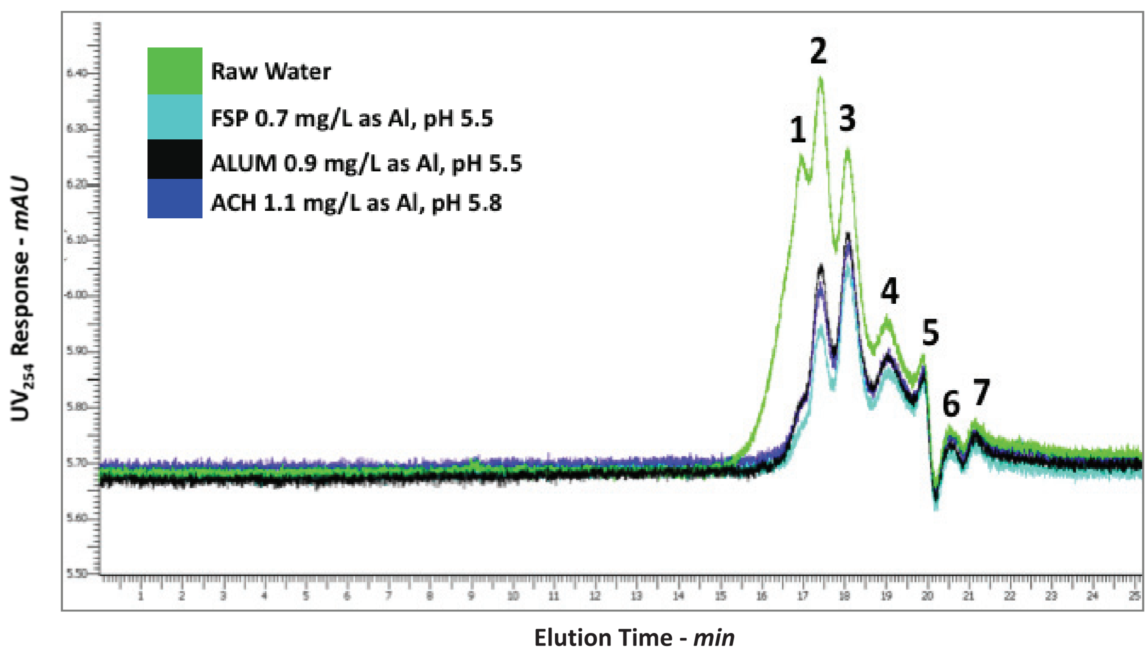


Figure 5.10 Representative **pilot-scale** SEC chromatogram comparing favourable ACH (HBNS) filtration conditions to same day baseline Alum pilot conditions and FSP operations. Fractions in the chromatograph are numbered for fraction identification.

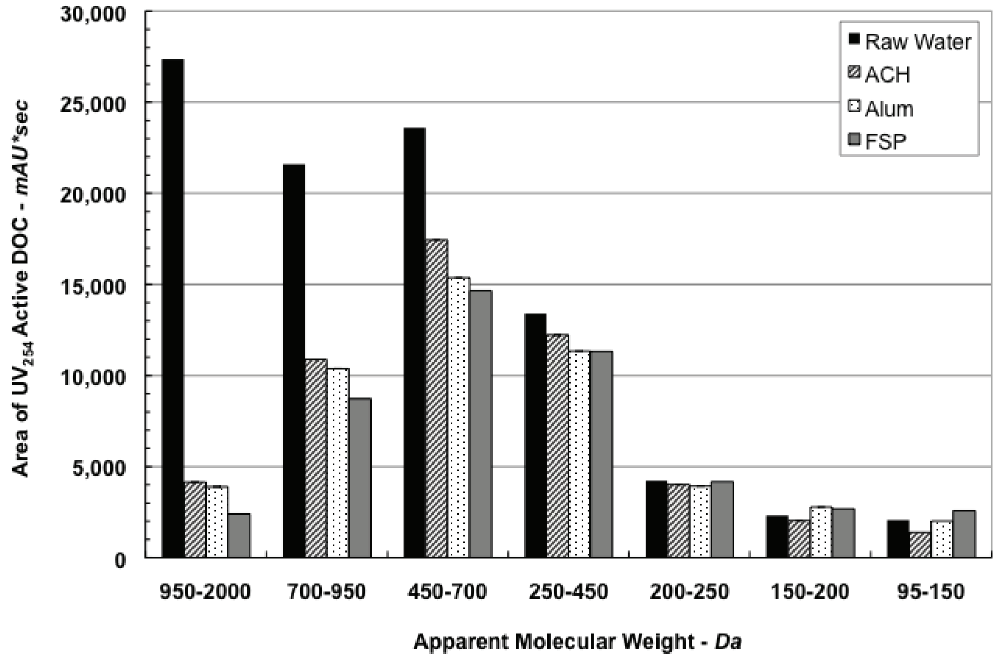
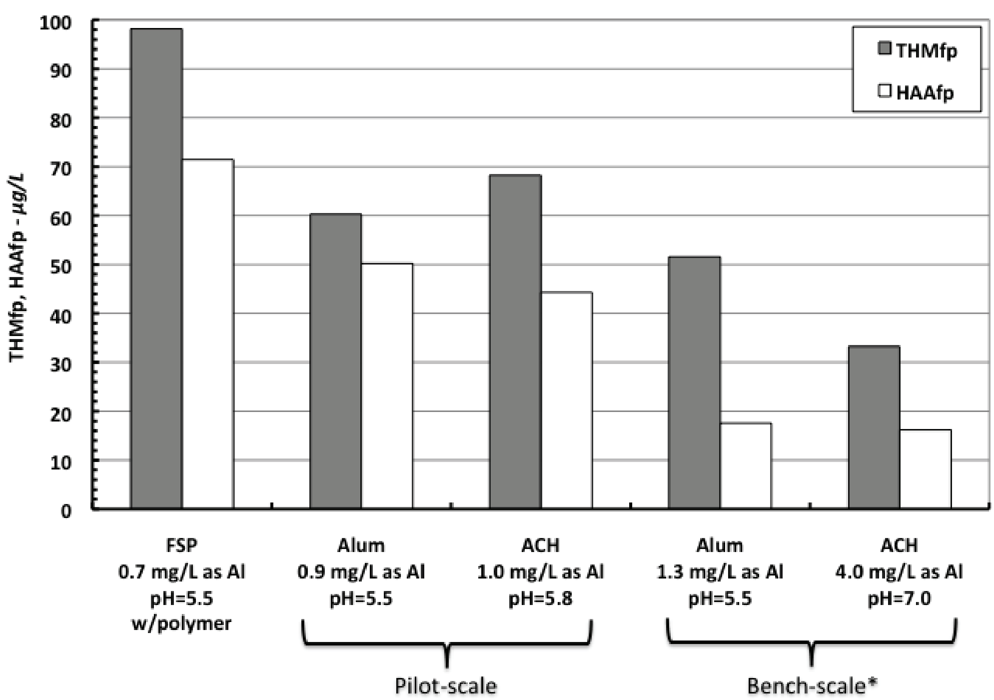


Figure 5.11 UV_{254} Active DOC (mAU*sec) in different MW fractions remaining following coagulation for favourable **pilot-scale** ACH (HBNS) filtration conditions and same day raw water, baseline Alum pilot conditions and FSP operations.



*FSP and plot-scale treatment processes included pre-chlorination practices and the bench-scale trials did not include pre-chlorination, therefore direct comparison between these treatment scales cannot be made.

Figure 5.12 THMFP and HAAFP results comparing **pilot-scale** superior ACH (HBNS) filtration performance to same day baseline pilot Alum and FSP performance and to bench-scale favourable organic matter removal performance for ACH (HBNS) and Alum.

CHAPTER 6 LEAD RELEASE FOR DRINKING WATER WITH HIGH CHLORIDE TO SULFATE MASS RATIOS

6.1. ABSTRACT

Bench-scale experiments investigated the role a coagulant change would have in causing a significant effect with respect to lead leaching in drinking water with a high (> 0.5) chloride-to-sulfate mass ratio (CSMR). The coagulants evaluated in this bench-scale study included aluminum sulfate (CSMR of 0.9), polyaluminum chloride (CSMR of 2.0) and ferric sulfate (CSMR of 0.9) and the two lead bearing plumbing materials examined were lead:tin solder and passivated lead pipe, both in connection with copper pipe. Although high CSMRs have been shown to be the main mechanism of attack in prior research, CSMR did not govern lead leaching following the coagulant changeover conditions evaluated in this study. Residual concentrations of iron and aluminum remaining following coagulation were principal contributors, as evidenced by positive correlations between lead release and iron and aluminum concentrations following stagnation. The overall influence of these two factors was dependent on the sources of lead in the plumbing scenarios tested. It was hypothesized that an important mechanism involved in the occurrence of lead release was related to the presence of iron and aluminum concentrations and the adsorption of lead on aluminum and iron oxides.

6.2. INTRODUCTION

A potential concern associated with coagulation optimization is the potential unintended consequences of a coagulant change on the distribution system, specifically related to lead release from lead pipe and solder materials. Previous studies have reported that coagulant changeovers were a key factor in unexpected high lead concentrations in distribution systems (Dodrill and Edwards, 1995; Edwards et al., 1999). Specifically, it was observed that coagulant switches from a sulfate containing coagulant (e.g., alum or aluminum sulfate) to a chloride containing coagulant (e.g., polyaluminum chloride or ferric chloride) resulted in lead release.

Evidence obtained through lead release data resulting from practical case studies and laboratory-based studies have demonstrated that a high CSMR induces high galvanic currents, which governs lead leaching incidences in distribution systems following coagulant changeovers (Dodrill and Edwards, 1995; Edwards et al., 1999; Dudi, 2004; Edwards and Triantafyllidou, 2007; Nguyen et al., 2010b; Nguyen et al., 2010c). The critical CSMR level cited from multiple bench-scale and full-scale studies that governs the effects of lead leaching is ~ 0.5 mg of chloride per mg of sulfate (Oliphant, 1983; Gregory, 1990; Dodrill and Edwards, 1995; Edwards et al., 1999; Edwards and Triantafyllidou, 2007). Above this CSMR level, galvanic corrosion of lead pipe is increased and below this threshold, lead leaching is mitigated.

The greatest impact of these anions was observed under stagnant conditions at lead to copper joints where low dissolved inorganic carbon and oxygen conditions exist, the local pH drops as low as 3 or 4 as Pb^{2+} (a lewis acid) is released and high corrosion rates prevail (Dudi, 2004; Edwards and Triantafyllidou, 2007; Nguyen et al., 2010a; Nguyen et al., 2010b). Chloride and sulfate concentrations have been identified in prior research as being highly influential in controlling water corrosivity upon lead under these circumstances (Edwards and Triantafyllidou, 2007; Stone et al., 2009; Nguyen et al 2010a; Nguyen et al 2010b).

The presence of either chloride or sulfate alone tends to protect leaded materials when there is no galvanic connection to another metal. However, where a lead to copper connection exists, chloride moves to the anode to maintain electroneutrality and stimulates the attack on lead pipe (Oliphant, 1983; Edwards and Triantafyllidou, 2007; Nguyen et al., 2010a). Further, chloride breaks down passivity by penetrating films through pores or defects easier than other ions such as sulfate (Reive and Uhlig, 2008). Through this process, chloride dissolves any coating or barrier previously on the lead surface and reacts with the lewis acid (Pb^{2+}) to form a soluble lead complex, $PbCl^{+}$. $PbCl^{+}$ increases the galvanic current for anodic dissolution, therefore increasing lead leaching and preventing the formation of solid barriers on the lead surface (Edwards and Triantafyllidou, 2007; Reive and Uhlig, 2008; Nguyen et al., 2010a). In contrast, if sufficient levels of sulfate are present, sulfate is drawn to the anode and protects the pipe during galvanic corrosion (Oliphant, 1983; Edwards and Triantafyllidou, 2007; Stone et al., 2009). $PbSO_4$ is insoluble at the local pH drop occurring at the anode, therefore through precipitation $PbSO_4$ serves as a corrosion inhibitor by strengthening the arrangement of the protective layer on the lead surface (Dudi, 2004; Edwards and

Triantafyllidou, 2007; Stone et al., 2009; Nguyen et al., 2010a).

The objective of this research was to investigate the role of a coagulant change in causing lead leaching in lead and/or copper plumbing. This work contributes to the established data set for coagulant changeover studies with a particular emphasis on very low alkalinity water (less than 10 mg/L as $CaCO_3$) and high CSMR values. This work was conducted at the bench-scale using a previously published methodology (Stone et al., 2009, Nguyen et al., 2010a). The coagulants studied in this paper include aluminum sulfate (alum), polyaluminum chloride (PACl) and ferric sulfate. In addition, two lead bearing plumbing materials studied were lead:tin solder and passivated lead pipe, both in connection with copper pipe.

6.3. MATERIALS AND METHODS

6.3.1. Experimental Procedures

The experimental approach was based on lead leaching studies in plumbing materials resulting from coagulant changeovers being conducted by lead researchers in this subject matter. (Stone et al. 2009; Nguyen et al., 2010a).

Apparatus. Bench-scale pipe set-ups were designed to compare the leaching effects of lead:tin solder and harvested lead pipe galvanically connected to copper pipe through two pipe set-ups. Previous studies have shown that lead solder and lead pipe galvanically connected to copper yielded the highest lead leaching instances when high CSMR is a factor (Nguyen et al., 2010a). One pipe set-up consisted of harvested lead pipe with a pre-existing pipe scale connected to copper using a simulated 40:60 lead:tin solder joint, which will be referred to in charts and tables as "Pb pipe – Pb:Sn solder – Cu pipe" and throughout this paper as the combined passivated lead and solder scenario. The lead pipe was harvested from a lead service line replacement in the distribution system in Halifax, Nova Scotia. The other pipe scenario consisted of a copper to copper pipe connection using a simulated 40:60 lead:tin solder joint, which will be referred to in charts and tables as "Cu pipe – Pb:Sn solder – Cu pipe".

The combined passivated lead and solder scenario was composed of a 31-cm (12.2-in) length of passivated 1.9-cm (0.75-in) lead pipe connected to a 6.35-cm (2.5-in) length of 1.3-cm (0.5-in) copper pipe using clear tubing and leaving an approximately 2-mm (0.08-in) gap between the two pipes (Figure 6.1). The lead to copper ratio for this scenario was in order of 6.6:1. The system containing only solder material as a source of lead was erected in the same manner, except the simulated solder joint was connecting two copper pipes (Figure 6.1). The lead to copper ratio for this scenario was in order of 1:139. To simulate a soldered joint, 0.08-cm (0.032-in) diameter solder wire was inserted through the 1.3-cm (0.5-in) copper pipe until it reached the interface of the two pipes. The solder and pipes were electrically connected using copper wires and clips to simulate a galvanic connection (Figure 6.2). The pipes were capped using silicone stoppers throughout the experiment. The pipe sizes and experimental set-up were selected to induce the worst-case scenario with respect to high corrosion and lead leaching conditions and to allow for micro-electrode measurements within the pipes (Nguyen et al., 2010a).

Test Water. Test water was collected from the JD Kline Water Treatment Plant (Halifax, Nova Scotia, Canada). This facility is a surface water treatment plant that draws water from the nearby Pockwock Lake. Test water was treated to simulate treatment conditions in the full-scale direct filtration treatment process (i.e.; coagulation, flocculation, filtration). All water conditions were subjected to identical treatment processes, with the only differences being the coagulant type, dosage and coagulation pH used. The coagulants evaluated included alum, ferric sulfate and PACl. The ferric sulfate dosage was calculated as an equivalent metal molar ratio based on the alum dosage currently employed in the full-scale treatment plant and the coagulation pH was determined through jar testing. The optimal coagulation pH and dosage for the PACl condition, a proprietary blend, were determined through jar testing. Pre-oxidized water was drawn from the full-scale plant and was subsequently coagulated, filtered through a 1.5 μm filter paper, and dosed with the following chemicals for final treatment: 1) zinc-orthopolyphosphate corrosion inhibitor/iron and manganese sequestering agent addition of 1.65 mg/L (0.5 mg/L as phosphate), 2) disinfectant addition of 1.0 mg/L total chlorine, and 3) final pH adjustment using 0.1M sodium hydroxide (NaOH) to 7.4. Treated water for each water condition was made in batches as required, but was only treated as far as the filtration stage. Finished water chemicals were added immediately before the water change occurred.

Since this study involved changing the coagulant type, dosage, and coagulation pH, the finished water alkalinity and organic content varied between the three water conditions tested. Table 6.1 presents the raw water and treated water quality characteristics for each water condition tested. The water condition treated with ferric sulfate was an outlier relative to coagulation performance, as it had twice the alkalinity and more TOC relative to the other coagulant conditions evaluated.

Protocol. During testing, the two pipe set-ups were exposed to the 3 water conditions described above. Each test was performed in duplicate to obtain statistical confidence in trends; therefore, 12 tests were conducted in total. Exposure of the finished water to each pipe condition was via a static "dump-and-fill" protocol three times per week. The water changes occurred on Monday (M), Wednesday (W) and Friday (F), therefore yielding two stagnation periods of 48 hours (M-W, W-F) and one stagnation time of 72 hours (F-M). Stagnation times were chosen based on previous research conducted in this field with the intention of representing the long stagnation times that commonly occur in public buildings over weekends (Nyugen et al 2010c). Over the 27-week duration of the experiment, the samples obtained after each water change were analyzed for bulk water pH, total lead content and chloride and sulfate levels. After week 17, samples were also filtered through 0.45 μm pore size filters and analyzed for dissolved lead concentrations. TOC and DOC concentrations, turbidity, pH, and alkalinity of batched and treated water were monitored throughout the experimental trial. The chloride and sulfate concentrations of finished water conditions were monitored before each water change to monitor CSMR conditions throughout the study.

Measurements of chloride and pH were attempted at the lead and copper material surface using micro-probe technologies to track further mechanisms of corrosive attack.

However, the measurement procedure had a negative effect on the experimental results, and these effects are described in the results section of this paper.

6.3.2. Analytical Procedures

Throughout the duration of this research, RO water was used for all cleaning and chemical stock preparations. All glassware was rinsed 3 times using RO water following cleaning. The RO water was obtained from a Milli-Q® purification system. Combination pH/ mV/ Temperature/ DO/ ISE and Conductivity meters (Accumet* XL 25 and XL 60 models) with plastic bodied, gel-filled, combination pH electrodes (Accumet Accu-Cap*) were used for pH readings. Three-point calibration (pH 4, 7, 10) was conducted each day. Alkalinity measurements were conducted using a Hach Alkalinity Test Kit (Model AL-DT) equipped with a digital titrator.

Lead samples were acidified using concentrated nitric acid and stored at 4°C until analysis. Samples were diluted as needed with concentrated nitric acid and analyzed using an atomic absorption graphite furnace (PerkinElmer Analyst 200). Unpreserved chloride and sulfate samples were analyzed with 5 days of sampling and were stored at 4°C until analysis. Chloride and sulfate analysis was completed using ion chromatography (Metrohm 761 Compact IC).

To validate the precision and accuracy of the metals and anions analysis, method blanks (deionized water) and quality control (QC) samples (deionized spiked with a known amount of standard mixture) were analyzed every 10 samples for metals analysis and every 15 samples for anion analysis. Recovery testing was carried out on the QC samples and results were only accepted if QC recoveries were between 70 to 130 %. In addition, samples obtained during weeks 4 through 9 were analyzed for metals via Induced Coupled Plasma Mass Spectrometry (ICP-MS), which provided both a QC analysis and an indication of background aluminum and iron concentrations remaining following coagulation for the conditions tested.

TOC and DOC samples were collected head-space free in 40-mL pre-cleaned glass vials and preserved with concentrated phosphoric acid to a pH <2 and measurements were performed using a TOC-V CPH analyzer with a Shimadzu ASI-V autosampler and catalytically aided combustion oxidation non-dispersive infrared detector (NDIR) having a method detection limit of 0.08 mg/L (Shimadzu Corporation, Kyoto, Japan). Before sample collection, DOC samples were filtered through 0.45 μm polsulfone filter membrane (GE Water & Process Technologies) that had been pre-rinsed with 500-mL of RO water (APHA, AWWA, and WEF, 1998).

6.4. RESULTS AND DISCUSSION

For all water conditions studied, the total lead entering the pipe set-ups was not detectable. Figure 6.3 presents the total lead released from each of the pipe scenarios throughout the 27 weeks of this study. The acclimation period for both pipe scenarios was 6 weeks and dissolved lead monitoring started after 4-months operation, to ensure that stability in the system had occurred.

The total lead spikes observed throughout the first 6 weeks for the combined passivated lead and solder pipes (Figure 6.3) can be attributed to lead particles sloughing off the passivated pipe during this initial acclimation phase and sitting at the bottom of the pipe set-up during stagnation, therefore causing increased lead concentrations in the sampled water. Additionally, lead spikes were observed in both pipe-setups in Week 11 following micro-electrode measurements (Figure 6.3a). In order to gain more insight into the localized effects at the lead and copper interface, chloride and pH micro-electrodes were placed inside the test pipes before the water was changed at the end of Week 10, which disturbed the lead surfaces within the pipes and increased lead levels in the following weeks. These lead spikes were caused by the electrodes scraping the lead pipe walls and disturbing the lead:tin solder. The increased lead release effects were significantly worse in the passivated lead pipe set-up, due to additional lead particles sloughing off the mature pipe scale inside of the pipe. Thus, microelectrode measurements were not collected for the remainder of the study. Following this disturbance, the lead release data returned to the apparent trends that were surfacing prior to the use of the microelectrodes after one or two weeks.

Generally, lead leaching was very high in this study (Figure 6.3), which was expected since all of the CSMR values exceeded the threshold value of ~ 0.5 to 0.6 for all water conditions tested (Nguyen et al., 2010a). Additionally, the geometry and physical experimental set-up were designed to maximize worst-case conditions contributing to lead corrosion. Based on the concept that CSMR is the controlling factor with respect to lead release, it was expected that the ferric sulfate (CSMR of 0.9) and alum (CSMR of 0.9) water conditions would lead to similar levels of lead leaching, since their CSMR levels were the same, and that the PACl treated water (CSMR of 2) would correlate with a higher lead release, since the CSMR level was more than double that of the other two water conditions (Table 6.1). The trends reported from this study did not support this hypothesis.

6.4.1. Pipe Set-up 1: Pb pipe – Pb:Sn solder – Cu pipe Scenario

Effect of CSMR. The ferric sulfate water was the most corrosive condition for the combined passivated lead and solder pipe set-up, whereas, the alum and PACl treated waters behaved similarly despite the large CSMR differences between the two water conditions (Figure 6.3a). For all conditions, the lead levels continued to decrease over time; however, more dramatic decreases were observed for the alum and PACl conditions, particularly in the first half of this study. The peak observed in weeks 24 through 25 for the alum water condition was likely a result of the lead solder being exposed to the atmosphere for maintenance of the simulated solder connection (Figure 6.3a). A small portion of the solder was replaced with new material to repair the solder joint.

Average lead release results were synthesized by averaging lead data throughout weeks 17 through 27 of this study (Figure 6.4a and Table 6.2). This time period was chosen to correspond with the measurement of dissolved lead. To assess the difference between average results, statistical significance was determined using a 95% confidence interval and a p-value limit of 0.15 was chosen to account for variability of corrosion (Nguyen et al., 2010a). The ferric sulfate condition released an average of approximately 2 times more total lead than the PACl and alum conditions (p-values < 0.01), releasing 916 μg/L of lead (Figure 6.4a and Table 6.2). The difference in average total lead for the alum and

PACl conditions were not significantly different (p-value of 0.70) and the 95% confidence intervals of the water conditions overlapped, however PACl lead release concentrations were higher, on average, throughout the study (Figure 6.3a).

Dissolved lead trends observed throughout the last 10 weeks of the study were significantly less than total lead concentrations (Figure 6.4a) indicating that the majority of the lead released was in a particulate form. On average, the dissolved lead concentrations were approximately 24% of the total lead measured in the passivated lead scenario. CSMR trends for dissolved lead release were somewhat different than total lead trends (Figure 6.4a). For the passivated lead scenario, the ferric sulfate condition remained the most corrosive condition and leached the highest levels of dissolved lead (p-value < 0.01), however the alum condition contributed 24% higher dissolved lead concentrations than the PACl condition (p-value < 0.01).

Effect of Residual Aluminum and Iron. The results obtained through the ICP-MS analysis of weeks 4 through 9 samples revealed positive correlations between total residual concentrations of iron and aluminum remaining following stagnation and total lead release data for the passivated lead scenario (Figure 6.5a). Furthermore, the trend line for a CSMR of 2 is steeper and yields more lead than predicted by the trendline associated with a CSMR of 0.9. This illustrates that the effects of CSMR on lead release were secondary to the effects of iron and aluminum concentrations. The average aluminum, iron and lead concentrations released during weeks 4 through 9 are presented in Table 6.3. It is hypothesized that the mechanism involved in the occurrence of lead release as a function of iron and aluminum concentrations is the adsorption of lead on aluminum and iron oxides.

Consistent with these findings, past and recent investigations involving both field testing and pipe loop experiments have concluded that particulate lead concentrations are positively correlated with particulate iron concentrations (Hulsmann, 1990; De Rosa and Williams, 1992; Deshommes et al., 2010; Triantafyllidou and Edwards, 2011). It is hypothesized that adsorption of lead on iron particles is a dominant cause of lead release in systems where particulate iron is entering the distribution system (Hulsmann, 1990; Deshommes et al., 2010). Additionally, it has been shown that the effects of particulate iron on lead release are very obvious following periods of stagnation and lead concentrations actually increased with stagnation but were not an issue during flowing conditions (Hulsmann, 1990).

6.4.2. Pipe Set-up 2: Cu pipe – Pb:Sn solder – Cu pipe Scenario

Effect of CSMR. Over the duration of the study, the variability in total lead release was such that no considerable difference could be seen among the water conditions for the pipe set-up containing lead:tin solder as the only lead bearing material (Figure 6.3b). Despite the CSMR differences, there was no considerable difference in average total lead concentrations between each water condition tested (Figure 6.4b and Table 6.2). However, the average alum lead release concentration was slightly higher than the ferric sulfate and PACl conditions (p-value < 0.03), releasing approximately 50-µg/L total lead, whereas the ferric sulfate and PACl lead concentrations were not significantly different (p-value of 0.2).

Dissolved lead trends were significantly less than total lead concentrations for the solder only scenario, again indicating that the majority of the lead released was in a particulate form (Figure 6.4b and Table 6.2). On average, the dissolved lead concentrations were approximately 45% of the total lead concentrations in the solder only scenario. For the solder only scenario, the alum condition remained the most corrosive environment, yielding 26% more dissolved lead than the PACl condition (p-value < 0.08) and 77% more than the least corrosive ferric sulfate condition (p-value < 0.01).

Effect of Residual Aluminum and Iron. Unlike the passivated lead results, iron and aluminum levels following stagnation did not correlate with total lead release data during weeks 4 through 9 for the solder only scenario (Figure 6.5b). One explanation for the lack of variability between coagulant conditions is that the detrimental effects associated with CSMR and residual iron and aluminum levels are masking each other, therefore yielding no effect on lead leaching. The average aluminum, iron and lead concentrations released during weeks 4 through 9 are presented in Table 6.3.

Effect of other water quality parameters on metals release. As outlined in Table 6.1, TOC, DOC and alkalinity levels following coagulation were higher for the ferric sulfate water condition as compared to the alum and PACl conditions and particulate organic matter is also present in the ferric sulfate condition and not in the others. However, lead release trends did not correlate with TOC or DOC changes that occurred between batched water conditions in either experimental set-up over the duration of the study. It was expected that increased alkalinity would buffer the low pH at the lead solder surface and help minimize lead levels. However, in this case, a higher alkalinity was associated with increased lead release, therefore the difference in alkalinity was not enough to provide sufficient buffering capacity to overcome the adverse effects of the residual iron and aluminum concentrations for the passivated lead scenario.

6.4.3. Comparison of Lead Materials

The combination of passivated lead and lead:tin solder resulted in significantly more lead release (on a mass basis, mg/L) than lead released from the presence of lead:tin solder alone (Figure 6.4). On average, the passivated lead pipe condition resulted in bulk water total lead concentrations 9 times more than the lead/tin solder to copper condition for alum, 13.5 times more for PACl and 33 times more for the ferric sulfate treated water (Figure 6.5). Bulk water lead concentrations were expected to be higher in the passivated lead pipes since there were two sources of lead (lead pipe and solder) and significantly more lead material was exposed to the water in the passivated lead apparatus versus the solder only scenario.

The higher levels of particulate lead in the passivated lead scenario could be attributed to plumbing scales being degraded despite the corrosion inhibitor presence (Table 6.3). It is hypothesized that the instability of the corrosion layer in the passivated pipe under these new treatment conditions led to a high occurrence of particulate lead and subsequently made this condition more vulnerable to the detrimental effects of the residual iron and aluminum concentrations than the solder only scenario. This explains why residual iron and aluminum concentrations were the primary contributor to lead release in the passivated lead scenario, but the effects of these cations were masked by the effects of

CSMR in the solder only scenario. The findings also suggest that iron and aluminum concentrations below regulatory levels may still pose a public health risk in distribution systems, particularly those with iron distribution pipes (Triantafyllidou and Edwards, 2011).

These results are not consistent with recent findings in a case study by Sandvig and Boyd (2010), which evaluated the effects of CSMR on the release of lead from a variety of lead plumbing materials and found that simulated lead solder to copper connections consistently yielded higher particulate lead concentrations than passivated lead pipe connected to copper. These inconsistencies are attributed to differences in the composition and stability of the existing scale on the passivated pipes used in these studies.

To directly compare the average lead released between plumbing scenarios, lead concentrations were normalized as the total mass of lead released per wetted lead material surface area in Figure 6.6. Normalized values were calculated by multiplying the total lead concentrations by the sample volume and dividing by the wetted surface area of leaded material (Nguyen et al., 2010a). The exposed surface area of lead and volume of water exposed to pipe material for each pluming scenario are presented in Table 6.4. The combined passivated lead and solder plumbing scenario contained approximately 100 times more wetted lead surface area than the solder only set-up.

The solder only pipe set-up had the highest lead levels for each water condition when compared to the passivated lead scenario on a lead released per unit surface area basis. Therefore, the galvanic connection of copper pipe soldered together with lead:tin solder exacerbated lead leaching. This is consistent with previous literature in which a lead solder to copper pipe loop consistently produced higher lead levels per wetted surface area than copper pipes coupled with passivated lead pipes under similar CSMR conditions (Nguyen et al., 2010a). The mass of lead released per wetted surface area from the solder only scenario was 4.3 times higher than the passivated lead scenario for the ferric sulfate condition, 10.5 times higher for the PACl condition and 16 times higher than the alum condition (Figure 6.6). The substantially higher lead release associated with the alum condition in the solder only scenario as compared to the combined passivated lead scenario may be attributed to the fact that the passivated lead pipes were exposed to similar water quality in this study as they would have been exposed to *in situ*.

Although galvanic currents were not measured as part of this study, there is evidence that suggests that significantly higher galvanic currents were sustained by the solder only pipe scenario. The increased mass of lead release per wetted surface area in the solder only pipe scenario is an indication that corrosion rates are significantly higher for the solder only pipe scenario. Also, the bulk water pH values following stagnation were 0.25 to 0.55 pH units lower in the solder only scenario. During stagnant conditions, the pH at the lead surface may decrease significantly and reach levels as low as 3 or 4 (Edwards and Triantafyllidou, 2007; Nguyen et al., 2010a). Since the micro-environment over which the pH drop occurs is very small (Nguyen et al., 2010b), even a slight decrease in the bulk water pH would indicate a local pH drop at the anode surface. Therefore, this drop in bulk water pH is indicative of a local pH drop at the anode and increased galvanic corrosion rates in the solder only scenario.

6.5. CONCLUSIONS

Bench scale experiments were conducted to investigate the role of high CSMRs in lead leaching from lead:tin solder and harvested lead pipe galvanically connected to copper. No definitive trends were observed relating CSMR to lead leaching; the highest CSMR condition (PACl with a CSMR of 2) did not yield the highest lead concentrations and the replicate CSMR conditions (alum and ferric sulfate with CSMRs of 0.9) did not yield similar lead levels. Although high CSMRs have been shown to be the main mechanism of attack in prior research, CSMR was not the primary catalyst for lead leaching following the coagulant changeover conditions evaluated in this study. Residual concentrations of iron and aluminum remaining following coagulation were principal contributors. The overall influence of these two factors was dependent on the sources of lead in the plumbing scenarios tested.

For the passivated lead pipe scenario, positive correlations were found between the total residual iron and aluminum concentrations following coagulation and total lead released during stagnation, for each coagulant tested. It was hypothesized that adsorption of lead on iron and aluminum oxides is the mechanistic explanation for this relationship. The ferric sulfate treated water was the most corrosive treatment condition, which correlated with the highest residual iron and aluminum concentrations following stagnation. CSMR effects were secondary to the corrosive effects of iron and aluminum, as evidenced by

PACl (CSMR of 2.0) yielding higher than predicted lead release trends than alum (CSMR of 0.9) despite having similar residual aluminum concentrations in the treated water. The lead release from the scenario where solder was the only lead source was not considerably different for the three water conditions tested. Thus there is potential that the detrimental effects of residual iron and aluminum counteracted the effects of CSMR for this condition.

The results of this research highlight the importance of ensuring corrosive factors (i.e.; CSMR and residual iron and aluminum) are not unintentionally introduced as a result of coagulant dosage adjustments or changeovers. Identifying the appropriate solutions to lead release remains a site-specific exercise, but should consider the unintended consequences of coagulation conditions on distribution system water quality.

Table 6.1 Average water quality characteristics for raw and treated water conditions. The error values indicate the 95% confidence interval.

Parameter	Raw Water	PACl	Alum	Ferric Sulfate
Coagulant Dosage (mg/L)	---	1.5	8.0	5.4
Coagulant Dosage (mg/L)	---	1.5 as Al	0.7 as Al	1.4 as Fe
Coagulation pH[1]	---	6.0	5.5	5.0
Alkalinity (mg/L as $CaCO_3$)	0	16.3 ± 1.6	16.8 ± 2.8	32.6 ± 7.4
TOC (mg/L)	2.89 ± 0.13	1.86 ± 0.57	1.88 ± 0.10	2.50 ± 0.20
DOC (mg/L)	2.82 ± 0.13	1.86 ± 0.55	1.81 ± 0.24	2.13 ± 0.41
CSMR	1.49	2.06 ± 0.25	0.93 ± 0.10	0.91 ± 0.10

[1]Finished water pH is 7.4.

Table 6.2 Average bulk water total and dissolved lead release concentrations (µg/L) for each water condition during Weeks 17 through 27 of this study (± standard deviation). Data from the duplicate pipes were averaged to obtain the comparisons in this table.

	Lead - *µg/L*	
Water Condition	**Total**	**Dissolved**
	Pb pipe – Pb:Sn Solder - Cu pipe	
Ferric Sulfate	916 ± 332	203 ± 81
PACl	497 ± 352	96 ± 21
Alum	422 ± 302	128 ± 45
	Cu pipe - Pb:Sn Solder - Cu pipe	
Ferric Sulfate	27 ± 28	5.6 ± 11
PACl	37 ± 27	20 ± 11
Alum	47 ± 19	27 ± 17

Table 6.3 Average bulk water total lead, aluminum and iron release data (µmol) for each water condition during Weeks 4 through 9 of this study (± standard deviation). Data from the duplicate pipes were averaged to obtain the comparisons in this table.

Water Condition	Total Lead - *µmol*	Total Aluminum - *µmol*	Total Iron - *µmol*
		Pb pipe – Pb:Sn Solder - Cu pipe	
Ferric Sulfate	9.3 ± 1.8	7.0 ± 0.5	12.8 ± 2.9
PACl	4.2 ± 3.5	5.1 ± 1.5	0
Alum	7.8 ± 14.9	9.8 ± 7.3	0
		Cu pipe - Pb:Sn Solder - Cu pipe	
Ferric Sulfate	1.2 ± 0.6	4.8 ± 0.6	15.4 ± 3.8
PACl	1.1 ± 0.8	1.2 ± 0.7	0
Alum	1.1 ± 0.6	3.1 ± 0.5	0

Table 6.4 Exposed lead and copper wetted surface area and volume of exposed water for each pipe condition.

Pipe Material	Surface Area of Lead Bearing Material Exposed (cm^2)	Surface Area of Copper Bearing Material Exposed (cm^2)	Volume of Water Exposed to pipes (mL)
Pb pipe – Pb:Sn solder – Cu pipe	158	24	74.5 ± 4
Cu pipe – Pb:Sn solder – Cu pipe	1.58	219	106 ± 2

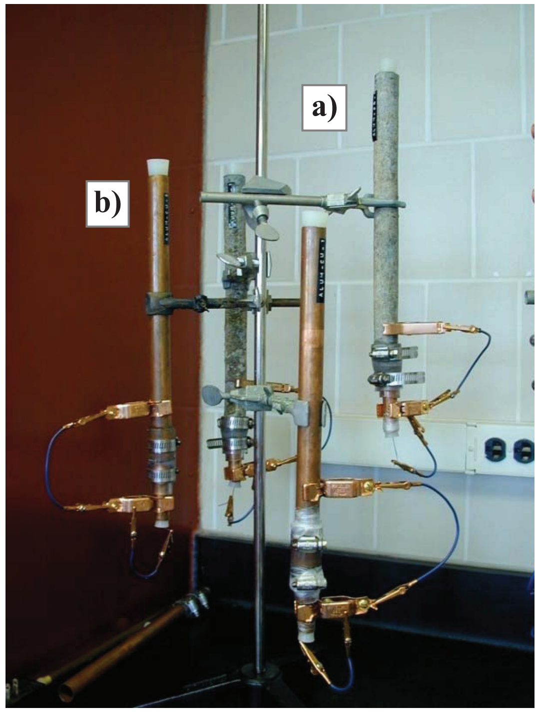
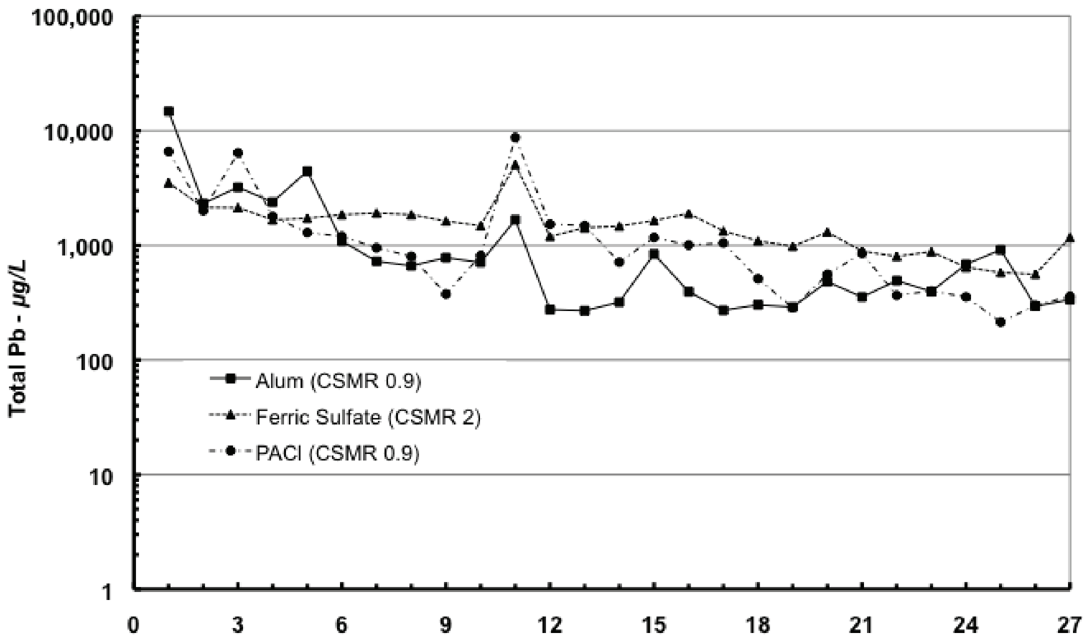


Figure 6.1 Picture of 4 of 12 pipe setups: a) Pipe set-up 1: Pb pipe – Pb:Sn solder – Cu pipe; b) Pipe set-up 2: Cu pipe – Pb:Sn solder – Cu pipe

Figure 6.2 Picture of simulated 40:60 Pb/Sn soldered joint.

a.) Pb pipe – Pb:Sn solder – Cu pipe



b.) Cu pipe – Pb:Sn solder – Cu pipe

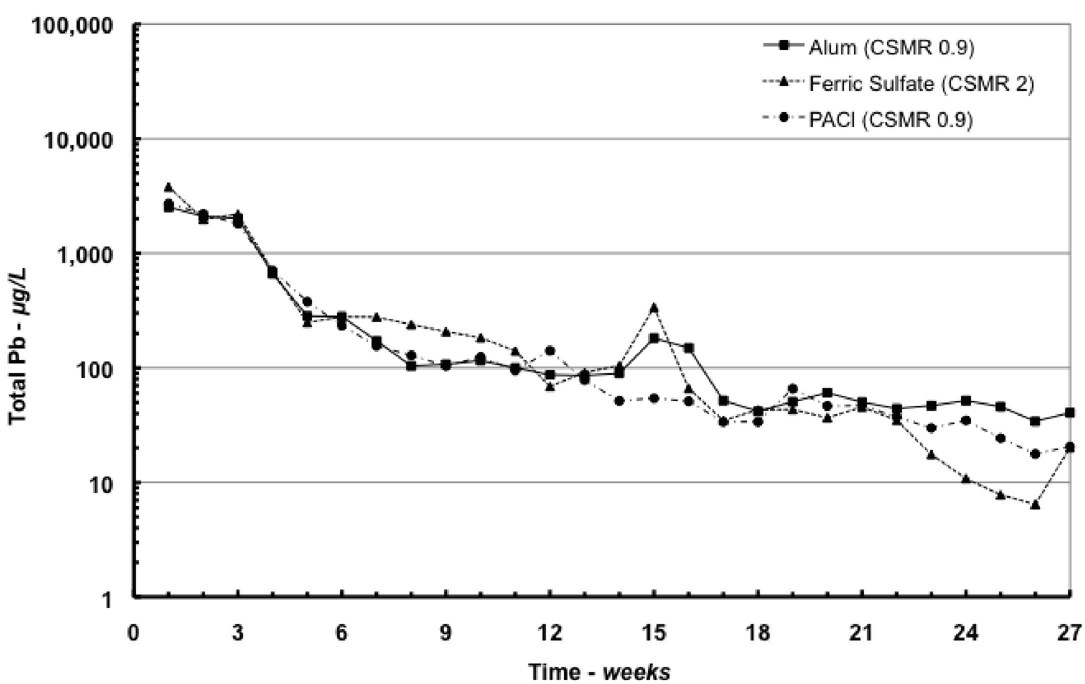


Figure 6.3 Total lead release as a function of time. Data from the three samples per week and duplicate pipes were averaged to obtain the comparisons in this figure.

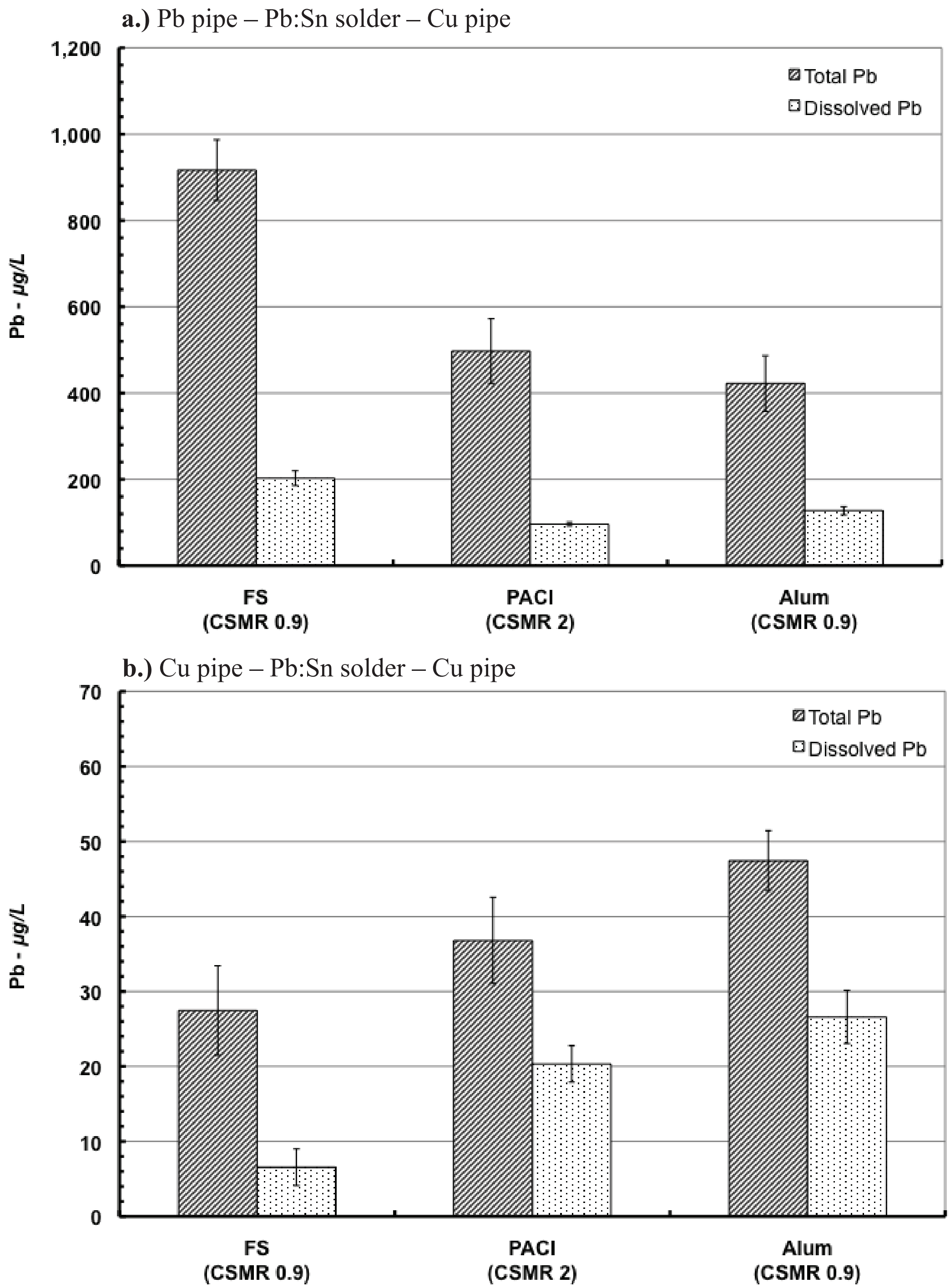


Figure 6.4 Average bulk water total and dissolved lead release concentrations (µg/L) for each water condition during Weeks 17 through 27 of this study. Data from the duplicate pipes were averaged to obtain the comparisons in this figure. The error bars indicate the 95% confidence interval.

(FS = ferric sulfate, PACl = polyaluminum chloride, Alum = aluminum sulfate)

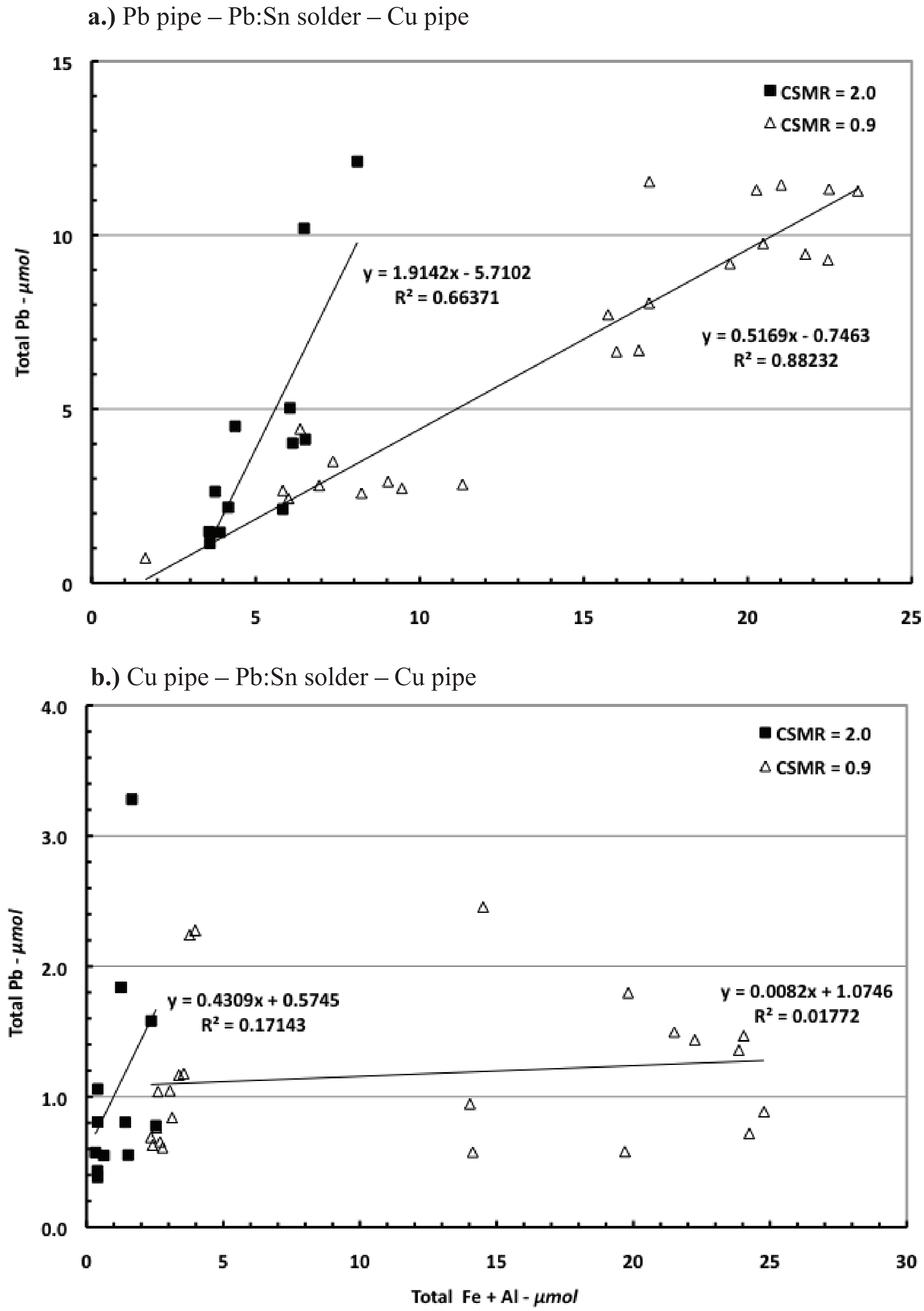


Figure 6.5 Average lead release as a function of iron and aluminum release for during Weeks 4 through 9 of this study. Data from the duplicate pipes were averaged to obtain the comparisons in this figure.

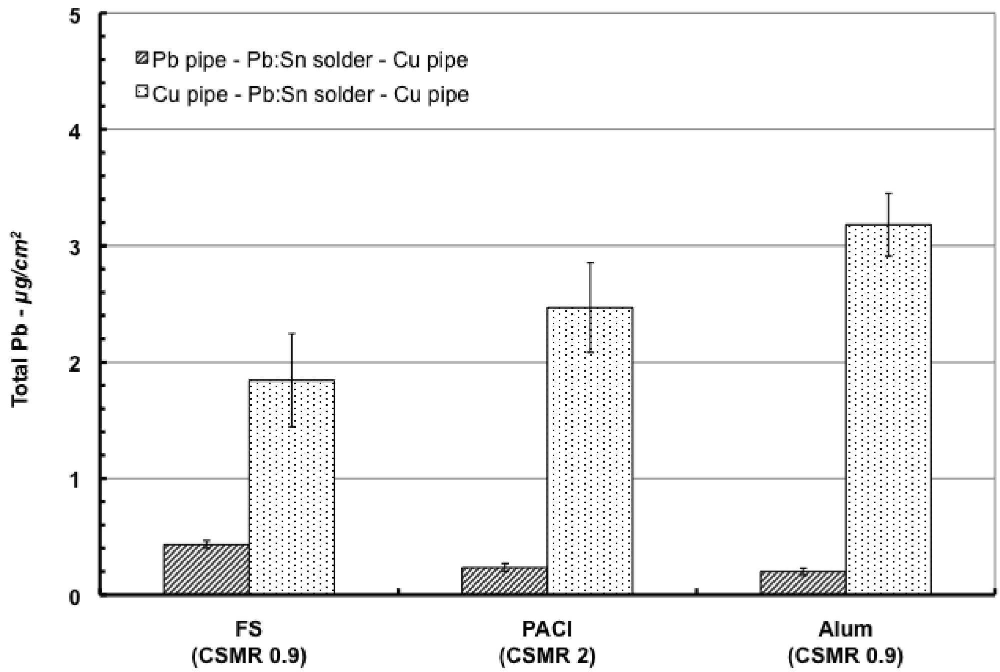


Figure 6.6 Average total mass of lead released per wetted surface area of lead bearing material (µg/cm^2) for each water condition during Weeks 17 through 27. Data from the duplicate pipes were averaged to obtain the comparisons in this figure. The error bars indicate the 95% confidence interval.

(FS = ferric sulfate, PACl = polyaluminum chloride, Alum = aluminum sulfate)

CHAPTER 7 INFLUENCE OF COAGULATION RESIDUALS ON LEAD RELEASE IN DRINKING WATER

7.1. ABSTRACT

Bench-scale experiments evaluated the corrosive effects of coagulation residuals following stagnation on lead:tin solder-to-copper connections under variable chloride-to-sulfate mass ratio (CSMR) conditions. CSMR conditions, both above and below the 0.5 CSMR threshold cited for lead leaching, were tested using three different coagulants; aluminum sulfate (CSMRs of 0.3 and 1.0), ferric sulfate (CSMRs of 0.3 and 0.9) and polyaluminum chloride (CSMR of 2.8). Both residual particulate iron and aluminum concentrations and CSMR levels were found to be significant factors contributing to lead release in galvanic settings. Overall, results suggest that iron particulates may play a more important role in lead release than aluminum particulates.

7.2. INTRODUCTION

Coagulant changeovers can inadvertently induce water chemistry changes that have significant detrimental impacts on distribution system water quality. Specifically, changes in coagulant type or dosage can introduce treated water residuals that have corrosive impacts on leaded materials in the distribution system. Unfavorable residuals that have been shown to have an effect on water corrosivity following a coagulant changeover include iron and aluminum oxides resulting from ineffective treatment conditions or increases in the chloride-to-sulfate mass ratio (CSMR) resulting from changing the coagulant type or dosage (Edwards et al., 2007; Nguyen et al 2010a;, Nguyen et al 2010c).

The correlation between galvanic corrosion and significant changes in pH, sulfate, chloride and lead concentrations following stagnation has been well established in recent literature (Edwards and Triantafllidou, 2007; Nguyen et al., 2010a; Nguyen et al., 2010b; Nguyen et al., 2010c). When lead and copper are coupled in distribution systems, the lead surface behaves anodically, galvanic currents persist and lead corrosion is induced. During stagnation, dissolved oxygen is depleted over time and acidic conditions at the anode are increased as Pb^{2+}, a lewis acid, is released. Consequently, the resulting pH conditions at the anodic surface can reach levels as low as 3-4, which hinders the formation of passive films, increases and sustains galvanic currents and perpetuates the attack of the lead material (Dudi, 2004; Edwards and Triantafyllidou, 2007; Nguyen et al., 2010a; Nguyen et al., 2010b).

Numerous case studies have demonstrated that the magnitudes of chloride and sulfate concentrations present under such galvanic conditions are a primary contributor to lead corrosion rates (Edwards and Triantafyllidou, 2007; Stone et al., 2009; Nguyen et al 2010a; Nguyen et al 2010b). Specifically, when the CSMR is high (CSMR > 0.5) chloride stimulates the attack of lead pipe; whereas, when the CSMR is low (CSMR < 0.5), the abundance of sulfate ions outweigh the negative impacts of chloride and act as a corrosion inhibitor (Oliphant, 1983; Gregory, 1990; Dodrill and Edwards, 1995; Edwards et al., 1999; Edwards and Triantafyllidou, 2007). In contrast, the results presented in Chapter 6 concluded that the CSMR was not always the controlling factor with respect to lead release in these corrosive microenvironments and demonstrated the importance of other water quality parameters on leaching incidences.

In Chapter 6, a bench-scale study was conducted to evaluate the effects of high CSMRs on lead leaching from passivated lead pipe and lead:tin solder coupled with copper pipe. While the CSMR did have a secondary impact on lead leaching in this study, lead concentrations following stagnation were significantly affected by the residual concentrations of iron and aluminum remaining following coagulation. The overall impact of these factors on lead release was dependent on the sources of lead in the plumbing scenarios tested. It was suggested that the mechanism involved in the occurrence of lead release was adsorption of lead on aluminum and iron oxides remaining after coagulation.

Anecdotal and field scale data presented in the literature has established a connection between particulate lead concentrations and particulate iron concentrations in distribution systems (Hulsmann, 1990; De Rosa and Williams, 1992; Deshommes et al., 2010; Triantafyllidou and Edwards, 2011). These studies hypothesized that adsorption of lead on iron particles is a dominant cause of lead release in systems where particulate iron is entering the distribution system (Hulsmann, 1990; Deshommes et al., 2010).

Study Objectives. The objective of this research was to investigate the role of CSMR and residual coagulation particles (i.e., remaining floc particles) in causing lead leaching under stagnant conditions when exposed to lead-to-copper connections in distribution systems. This study was carried out at the bench-scale using a previously published methodology (Nguyen et al., 2010a. Nguyen et al., 2010c). The three coagulants tested were aluminum sulfate (alum), polyaluminum chloride (PACl) and ferric sulfate under variable CSMR conditions. This experimental work was conducted to supplement the findings of Chapter 6 which uncovered the influence of iron and aluminum residuals as a prominent contributor to lead leaching under galvanic conditions for high CSMR source waters. Two distinct experimental phases were conducted to 1. verify the lead release trends reported in Chapter 6 using an augmented experimental setup and 2. explore the overall effect on lead release by lowering the CSMR of the sulfate based coagulants to levels below the 0.5 threshold reported to mitigate lead leaching in past studies (Nguyen et al., 2010a, Nguyen et al., 2010c).

7.3. MATERIALS AND METHODS

7.3.1. Experimental Procedures

The experimental design and procedure was based on lead leaching studies in plumbing materials resulting from coagulant changeovers being conducted by lead researchers in this subject matter. (Nguyen et al., 2010a, Nguyen et al., 2010c).

Apparatus. Simulated lead-copper joints were prepared using a 2.54-cm (1-in) length of 1.27-cm (0.5-in) diameter copper coupled with a 2.54-cm (1-in) length of 50:50 Pb:Sn solder melted inside (Figure 7.1). The lead to copper mass ratio for the coupons was in order of 1:7.2. The coupons will supplement the findings from the more mechanistic pipe apparatus used in Chapter 6 using this source water. Although the pipe set-up apparatus provided insight into the role a coagulant change would have in causing a significant effect with respect to lead leaching, this set-up might not reflect the magnitude of lead from lead:solder joints.

Test Water. Test water was collected from the JD Kline Water Treatment Plant (Halifax, Nova Scotia, Canada) and was treated to simulate treatment conditions in the full-scale direct filtration treatment process (i.e.; coagulation, flocculation, filtration). All water conditions were subjected to identical treatment processes, with the only differences being the coagulant type, dosage and coagulation pH used. The coagulants evaluated included alum, ferric sulfate and PACl. Pre-oxidized water was drawn from the full-scale plant and was subsequently coagulated, filtered through a 1.5 μm filter paper, and dosed with the following chemicals for final treatment: 1) zinc-orthopolyphosphate corrosion inhibitor/iron and manganese sequestering agent addition of 1.65 mg/L (0.5 mg/L as phosphate), 2) disinfectant addition of 0.5 mg/L total chlorine, and 3) final pH adjustment using sodium hydroxide to 7.4. Treated water was made in batches as required, but was only treated as far as the filtration stage. Finished water chemicals were added immediately before the water change occurred.

Two phases of experimentation were carried out in which changing the dose of the coagulant altered the CSMR. In Phase 1, the "high CSMR" phase, the coupons were initially exposed to three different water conditions including alum (CSMR of 1.0), PACl (CSMR of 2.8) and ferric sulfate (CSMR of 0.9). The ferric sulfate dosage was calculated as an equivalent metal molar ratio based on the alum dosage currently employed in the full-scale treatment plant and the coagulation pH was determined through jar testing (Table 7.1). The optimal coagulation pH and dosage for the PACl condition, a proprietary blend, were determined through jar testing. Finally, the alum pH and dose (pH of 5.5; alum dose of 8-mg/L) used were equivalent to full-scale operating conditions. In Phase 2, the "low CSMR" phase, the CSMR of the ferric sulfate and alum water conditions were altered to 0.3 (< 0.5 threshold) and the PACl treatment condition remained at the CSMR used in the high CSMR phase and behaved as a control condition to compare the two phases of the study (Table 7.1). The test water from the high CSMR phase remained stagnant for approximately one month before the low CSMR water conditions were introduced.

Since this study involved changing the coagulant type, dosage, and coagulation pH, the finished water alkalinity and organic content varied between the three water conditions evaluated. However, these water quality conditions did not impact the amount of lead released during stagnation (Appendix D, Figure D1). Table 7.1 presents the coagulation treatment conditions and treated water quality characteristics for each water condition tested.

Protocol. The solder-copper couplings were exposed to 100 mL of the finished water in a 200 mL glass beaker via a static "dump-and-fill" protocol two times per week, which provided one 72 hour stagnation period and one 96 hour stagnation time. Stagnation times were chosen based on previous research conducted in this field with the intention of representing the long stagnation times that commonly occur in public buildings over weekends (Nyugen et al 2010c). The tests were performed in triplicate for each water condition. The samples obtained after each water change were analyzed for bulk water pH, oxidation reduction potential (ORP), total and dissolved lead and copper concentrations. The TOC, turbidity, pH, ORP and alkalinity of batched and finished water were monitored periodically throughout. The chloride and sulfate concentrations of finished water conditions were monitored before each water change to verify influent CSMR conditions throughout the study. Finally, total and dissolved iron and aluminum concentrations were measured for a short period of time during the low CSMR study.

7.3.2. Analytical Procedures

Throughout the duration of this research, RO water was used for all cleaning and chemical stock preparations. All glassware was rinsed 3 times using RO water following cleaning. The RO water was obtained from a Milli-Q® purification system. Combination pH/ mV/ Temperature/ DO/ ISE and Conductivity meters (Accumet* XL 25 and XL 60 models) with plastic bodied, gel-filled, combination pH electrodes (Accumet Accu-Cap*) and a platinum pin Ag/AgCl combination ORP electrode (Accumet* Metallic ORP Combination Electrode) were used for pH and ORP readings, respectively. Three-point calibration (pH 4, 7, 10) was conducted each day for pH. Alkalinity measurements were conducted using a Hach Alkalinity Test Kit (Model AL-DT) equipped with a digital titrator.

Lead and copper samples were acidified using concentrated nitric acid and stored at 4°C until analysis. Samples were diluted with nitric acid and analyzed using an atomic absorption graphite furnace (PerkinElmer Analyst 200). Bulk water samples were filtered through 0.45 μm pore size filters and then analyzed for dissolved lead and copper concentrations. Unpreserved chloride and sulfate samples were analyzed with 5 days of sampling and were stored at 4°C until analysis. Chloride and sulfate analysis was completed using ion chromatography (Metrohm 761 Compact IC).

To validate the precision and accuracy of the metals and anions analysis, method blanks (deionized water) and quality control (QC) samples (deionized spiked with a known amount of standard mixture) were analyzed every 10 samples for metals analysis and every 15 samples for anion analysis. Recovery testing was carried out on the QC samples and results were only accepted if QC recoveries were between 70 to 130 %. In addition, a small number of samples from the low CSMR study were analyzed for iron and manganese via Induced Coupled Plasma Mass Spectrometry (ICP-MS).

TOC and DOC samples were collected head-space free in 40-mL pre-cleaned glass vials and preserved with concentrated phosphoric acid to a pH <2 and measurements were performed using a TOC-V CPH analyzer with a Shimadzu ASI-V autosampler and catalytically aided combustion oxidation non-dispersive infrared detector (NDIR) having a method detection limit of 0.08 mg/L (Shimadzu Corporation, Kyoto, Japan). Before sample collection, DOC samples were filtered through 0.45 μm polsulfone filter membrane (GE Water & Process Technologies) that had been pre-rinsed with 500-mL of RO water (APHA, AWWA, and WEF, 1998).

7.4. RESULTS AND DISCUSSION

For all water conditions tested, the total lead entering the coupon set-ups was not detectable. Figure 7.2a presents the total lead released over the 10-week duration of the high CSMR study. Figure 7.2b illustrates the total lead released during the 14-week low CSMR investigation. The acclimation period for both phases was approximately 4 weeks and it was assumed that system stability occurred past this point. Average lead concentrations were synthesized by averaging data throughout Weeks 5 through 10 of the high CSMR study period and weeks 5 through 14 for the low CSMR study period. To assess the difference between average results, statistical significance was determined using a p-value limit of 0.15 to account for variability of corrosion (Nguyen et al., 2010a).

7.4.1. High CSMR Results

Comparison of Coagulants. All CSMR values exceeded the threshold value of 0.5 mg of chloride per mg of sulfate for the water conditions tested in the high CSMR phase. For total lead release, the ferric sulfate treated water (CSMR of 0.9) presented the most corrosive conditions, the PACl test water (CSMR of 2.8) was the second highest contributor, and the lowest concentrations were observed for the aluminum sulfate water condition (CSMR of 1.0), as illustrated in Figure 7.2a. Following the acclimation stage, the ferric sulfate and PACl lead release concentrations were quite variable for the duration of the study, whereas the alum lead release trends were relatively stable (Table 7.2).

The ferric sulfate treated water resulted in 2.7 times more total lead than the PACl condition (p-value of 0.08) and 15 times more total lead than the alum condition (p-value of < 0.01), releasing 844 μg/L on average (Figure 7.3). In contrast to total lead release trends, the ferric sulfate and PACl dissolved lead concentrations were not significantly different (p-value of 0.9) and the 95% confidence intervals overlapped. The alum condition remained the least corrosive condition, leaching an average of 6.8 times less dissolved lead than the other conditions tested. On average, dissolved lead concentrations were 26% of the total lead concentrations for the ferric sulfate condition, 57% for the PACl treated water and 39% for the alum condition. This indicates that a significant amount of particulate lead is being released, particularly for the ferric sulfate condition. The high concentrations of particulate lead are consistent with other studies evaluating the corrosion of lead solder in connection with copper (Nguyen et al., 2010a). There was a considerable amount of variability in lead release data for the ferric sulfate water condition, due to high variability in lead concentrations throughout the study and amongst the triplicate coupons (Table 7.2).

No positive correlation exists between CSMRs and lead concentrations for the high CSMR conditions studied. However, the lead release trends associated with specific coagulant conditions in this study are consistent with the results of previous bench-scale corrosion studies using this source water under identical treatment conditions, but using a different experimental set-up (Chapter 6). In Chapter 6, it was concluded that the absence of CSMR correlation with lead release was a direct result of the adsorption of lead on residual concentrations of iron and aluminum oxides following coagulation.

Effect of Residual Aluminum and Iron. Iron and aluminum concentrations following stagnation were not measured during the high CSMR phase of this study, but a representative idea of the treated water concentrations of these coagulation residuals can be drawn from the results of Chapter 6 using the same source water. Table 7.3 presents the average treated water total aluminum and iron concentrations (μmol) for each water condition tested in Chapter 6 under similar treatment conditions as those tested in the high CSMR phase of this study. Based on the iron and aluminum concentrations reported in Table 7.3, it was hypothesized that the high levels of lead leaching observed following exposure to water treated with ferric sulfate was due to high residual iron concentrations remaining following coagulation. In addition, it was theorized that CSMR effects were secondary to the corrosive effects of iron and aluminum residuals, as evidenced by PACl (CSMR of 2.0) being consistently more corrosive than alum (CSMR 0.9), regardless of residual aluminum concentrations following coagulation being slightly higher for the water treated with alum.

It is important to note the lead release results reported in Chapter 6 were not considerably different for the three water conditions tested when exposed to lead:tin solder connected to copper and it was concluded that the detrimental effects of residual iron and aluminum counteracted the effects of CSMR. The differences in lead release trends and the overall magnitude of lead release resulting from the connection of lead:tin solder-to-copper observed between this study and the results presented in Chapter 6 can be explained by the difference in lead to copper ratios and fundamental differences in the experimental set-ups used. The lead-to-copper ratio utilized in this study was in the order of 20 times higher than the relative quantities used in Chapter 6 experiments and this study utilized soldered joints as opposed to simulated soldered connections.

7.4.2. Low CSMR Results

Comparison of Coagulants. Recent research indicates that lead release problems occurring following coagulant changeovers could typically be mitigated by controlling the type of coagulant and keeping the CSMR below the 0.5 threshold (Nguyen et al., 2010). Therefore, the ferric sulfate and alum CSMRs were lowered to 0.3 to evaluate the effect of a low CSMR on lead release. Although lead release was reduced, it was not mitigated. The ferric sulfate (CSMR of 0.3) and PACl (CSMR of 2.8) treated waters produced similar lead release concentrations despite the large CSMR differences (Figure 7.3), however, the ferric sulfate treated water was still the most corrosive environment over the duration of the low CSMR study (Figure 7.2b). Consistent with the high CSMR phase, the alum water condition (CSMR of 0.3) was the least corrosive environment (Figure 7.3). The ferric sulfate condition released 1.3 and 5.2 times more lead than the PACl (p-value of 0.06) and alum (p-value < 0.01) treated waters, respectively. Again, there was a considerable amount of variability in total lead release data for the ferric sulfate treated water, due to daily concentration variability and between the triplicate coupons (Table 7.2).

As was the case for the high CSMR study, dissolved lead concentrations were significantly less than total lead concentrations for all coagulant conditions tested. The ferric sulfate and PACl dissolved lead concentrations were not significantly different (p-value of 0.8) and the alum condition remained the least corrosive condition, leaching approximately 5 times less dissolved lead than the other conditions. On average, dissolved lead concentrations were 42% of the total lead concentrations for the ferric sulfate condition, 60% for the PACl treated water and 47% for the alum condition.

Effect of Residual Aluminum and Iron. Average bulk water total lead, aluminum and iron release data (μmol) for each water condition during Weeks 3-5 of the low CSMR phase are presented in Table 7.4. Analysis of these results revealed no linear relationship was observed for the ferric sulfate treated water conditions. Positive correlations (p-values <0.05) existed between particulate iron and aluminum remaining following stagnation and particulate lead release data for both the PACl and alum treated water during the low CSMR phase (Figure 7.4b and c), suggesting that adsorption of lead to iron and aluminum oxides was indeed occurring for these coagulant conditions.

It was hypothesized that particulate lead release did not correlate with total particulate iron and aluminum concentrations for the ferric sulfate condition because the detrimental effects associated with the high residual iron and aluminum levels were dampened by the beneficial effects of lowering the CMSR below the 0.5 threshold. In spite of this dampening effect, ferric sulfate was still the most corrosive water condition. The PACl treatment condition was the second highest contributor to lead release, despite having both very high particulate aluminum concentrations following stagnation and almost 10 times the CSMR of the ferric sulfate treated water. This suggests that iron particles may be more detrimental to lead release than aluminum particles. As expected, the aluminum sulfate condition was the least corrosive environment and was associated with the lowest particulate residual iron and aluminum particulates and CSMR condition.

The high and low CSMR results could not be directly compared since passivation of the lead surface occurred during stagnant conditions between the two experimental phases (approximately 1 month) and as the coupons were exposed to the various water conditions over time. The effects of passivation are highlighted by the difference in lead leaching observed for the PACl water conditions between phase 1 and phase 2, despite the CSMR conditions and residual aluminum and iron concentrations being identical. In fact, both total and dissolved average lead concentrations were approximately 3.5 times higher during the high CSMR phase for the PACl water condition.

7.4.3. Effect of Other Water Quality Parameters on Metals Release

Additional water quality parameters monitored throughout this study were TOC, DOC, alkalinity and ORP. Although TOC, DOC and alkalinity concentrations varied among the coagulant conditions tested, neither lead or copper release trends correlated with the treated water TOC, DOC or alkalinity concentrations of the treated water conditions (Appendix D, Figure D1). Therefore, organic matter and alkalinity were not considered to be a controlling factor in this study. However, the relatively low alkalinity (<20 mg/L as $CaCO_3$) of the treated water conditions throughout this study likely contributed to the high lead levels, since a low buffering capacity is expected to amplify the pH drop at the lead anode (Edwards and Triantafyllidou, 2007) and finished water alkalinities less than 50 mg/L have been shown to lead to serious lead problems (Nguyen et al., 2010a; Nguyen et al., 2010c).

Figure 7.5 presents the ORP of the treated water conditions and the average decrease in ORP that occurred during stagnation for both the high and low CSMR water conditions tested. A decrease in ORP is an indication that the solution is donating electrons to maintain electroneutrality. The overall decrease in ORP in the PACl and alum water conditions were generally higher than that of the FS condition indicating that more electron exchange occurred during these conditions. This electrochemical response could be an indication of the flow of chloride and sulfate ions to the anodic surface.

There most dramatic decrease in ORP occurred in PACl treated water, which also coincided with the highest treated water ORP conditions. For this condition, the decrease is an indication of chloride moving to the anodic surface and perpetuating the attack of the lead surface. The second largest treated water ORP and overall ORP reduction was observed in the alum treated water. In this case, the reduction in ORP is an indication of sulfate moving to the lead surface and protecting the solder surface. Hence, the dissolution of lead into the water was reduced for the alum treated water. The lowest treated water ORP and smallest change in ORP occurred for the ferric sulfate treated water, which is an indication that movement of sulfate to the anode was impeded and, therefore, hindered passivation of the lead surface.

7.5. CONCLUSIONS

Solder-to-copper coupons were exposed to variable coagulation conditions to evaluate the effects of coagulation residuals on lead leaching following stagnation. Consistent with the results of Chapter 6, residual aluminum and iron concentrations following stagnation and the treated water CSMR were both significant contributors to lead release trends. The positive correlations shown between particulate iron and aluminum and particulate lead concentrations following stagnation confirmed that the adsorption of lead to iron and aluminum oxides is a viable hypothesis for lead release.

Despite the variable CSMR conditions tested, ferric sulfate treated water (CSMR of 0.9 and 0.3) consistently yielded the highest lead levels following stagnation, due to high residual iron concentrations remaining following coagulation. CSMR effects were secondary to the corrosive effects of particulate iron, as evidenced by PACl (CSMR of 2.8) being consistently more corrosive than alum (CSMR 0.9 and 0.3), regardless of residual aluminum concentrations following coagulation. In general, results suggest that iron particulates may be more detrimental to lead release than aluminum particulates.
Problems occurring following coagulant changeovers cannot always be mitigated by controlling the type of coagulant and keeping the CSMR below the 0.5 threshold, as

suggested by past studies (Nguyen et al., 2010). If a utility is planning a coagulant changeover, the effects of coagulation residuals on distribution water quality should be verified before such changes are implemented at full-scale.

Table 7.1 Average water characteristics for treated water conditions. The error values indicate the 95% confidence interval.

Test Water	Coagulation Conditions			Alkalinity *(mg/L as $CaCO_3$)*	ORP *(mV)*	TOC *(mg/L)*	DOC *(mg/L)*	CSMR
	Dosage *(mg/L)*	Dosage *(mg/L)*	pH[1]					
High CSMR								
Ferric Sulfate	5.4	1.4 as Fe	5.0	15.1 ± 6.7	494 ± 26	2.631 ± 0.28	2.229 ± 0.12	0.93 ± 0.07
PACl	1.5	1.5 as Al	6.0	12.6 ± 8.4	618 ± 14	1.800 ± 0.27	1.838 ± 0.02	2.79 ± 0.18
Alum	8	0.7 as Al	5.5	11.4 ± 4.5	565 ± 22	2.091 ± 0.26	2.040 ± 0.06	0.99 ± 0.04
Low CSMR								
Ferric Sulfate	30	7.8 as Fe	5.0	6.2 ± 1.5	474 ± 18	1.786 ± 0.08	1.897 ± 0.09	0.300 ± 0.006
PACl	1.5	1.5 as Al	6.0	14.4 ± 2.4	567 ± 15	2.157 ± 0.10	2.191 ± 0.09	2.760 ± 0.100
Alum	50	4.4 as Al	5.5	5.3 ± 0.7	569 ± 18	2.067 ± 0.08	2.264 ± 0.01	0.300 ± 0.003

[1]Finished water pH is 7.4.

Table 7.2 Bulk water total and dissolved lead release concentrations (µg/L) for the high CSMR (Weeks 5 through 10) and low CSMR (Weeks 5 through 14) water conditions tested (± standard deviation). Data from the triplicate conditions were averaged to obtain the comparisons in this table.

	Lead - *µg/L*	
Water Condition	**Total**	**Dissolved**
	High CSMR	
Ferric Sulfate (CSMR 0.9)	844 ± 715	184 ± 188
PACl (CSMR 2.8)	314 ± 164	171 ± 94
Alum (CSMR 1.0)	56 ± 11	27 ± 4
	Low CSMR	
Ferric Sulfate (CSMR 0.3)	118 ± 19	49 ± 9
PACl (CSMR 2.8)	88 ± 6	53 ± 4
Alum (CSMR 0.3)	23 ± 3	11 ± 2

Table 7.3 Average treated water total aluminum and iron concentrations (µmol) for each water condition during Chapter 6 experiments under identical treatment conditions as those tested in the High CSMR phase of this study (± standard deviation).

Water Condition	**Total Aluminum *µmol***	**Total Iron *µmol***
Ferric Sulfate	5.2 ± 0.5	14.8 ± 4.1
PACl	1.1 ± 0.4	0
Alum	4.1 ± 0.6	0

Table 7.4 Average bulk water total lead, aluminum and iron release data (µmol) for each water condition during Weeks 3-5 of the Low CSMR phase (± standard deviation). Data from the triplicate conditions were averaged to obtain the comparisons in this table.

Water Condition	**Particulate Lead *µmol***	**Particulate Aluminum *µmol***	**Particulate Iron *µmol***
Ferric Sulfate	0.45 ± 0.29[1]	0.20 ± 0.22	0.65 ± 0.30
PACl	0.27 ± 0.18	0.47 ± 0.55	0.04 ± 0.03
Alum	0.08 ± 0.03	0.17 ± 0.17	0.03 ± 0.03

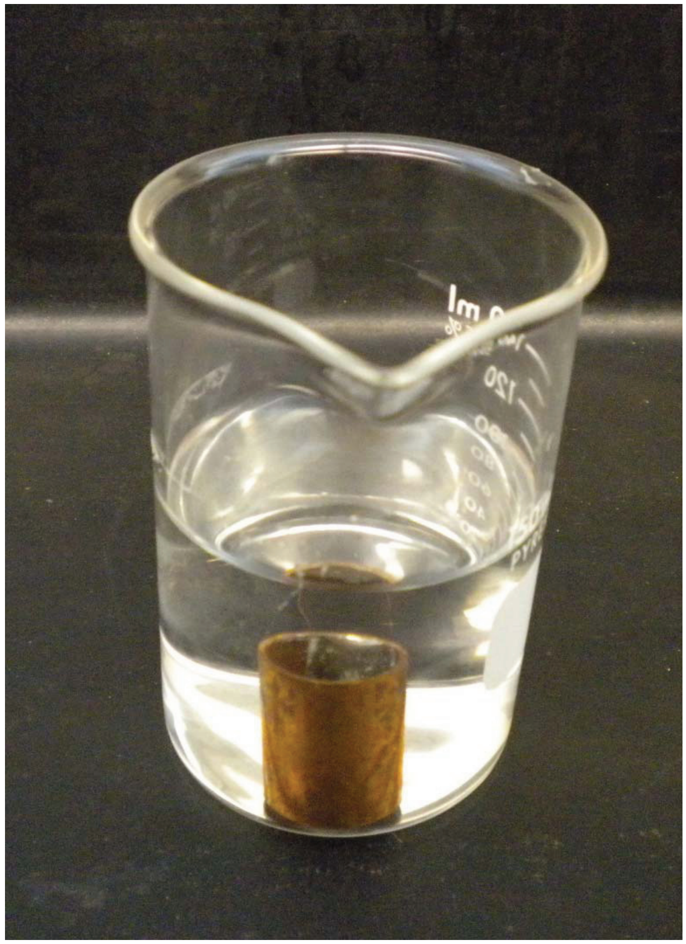
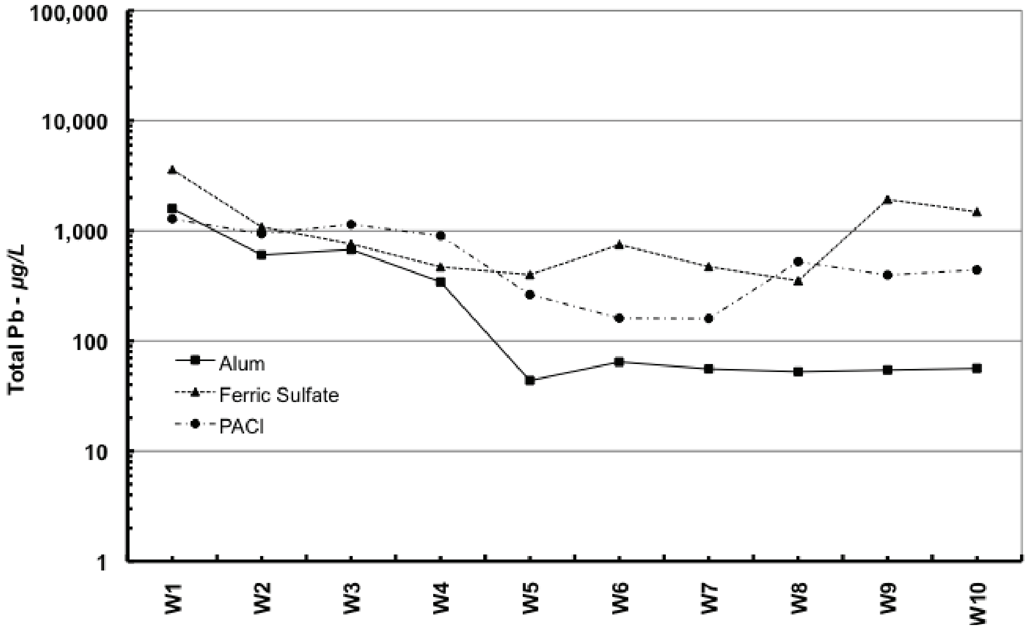


Figure 7.1 Picture of 50:50 lead/tin solder melted to a copper coupon and submerged in 100ml of test water in a glass beaker.

a.) High CSMR



b.) Low CSMR

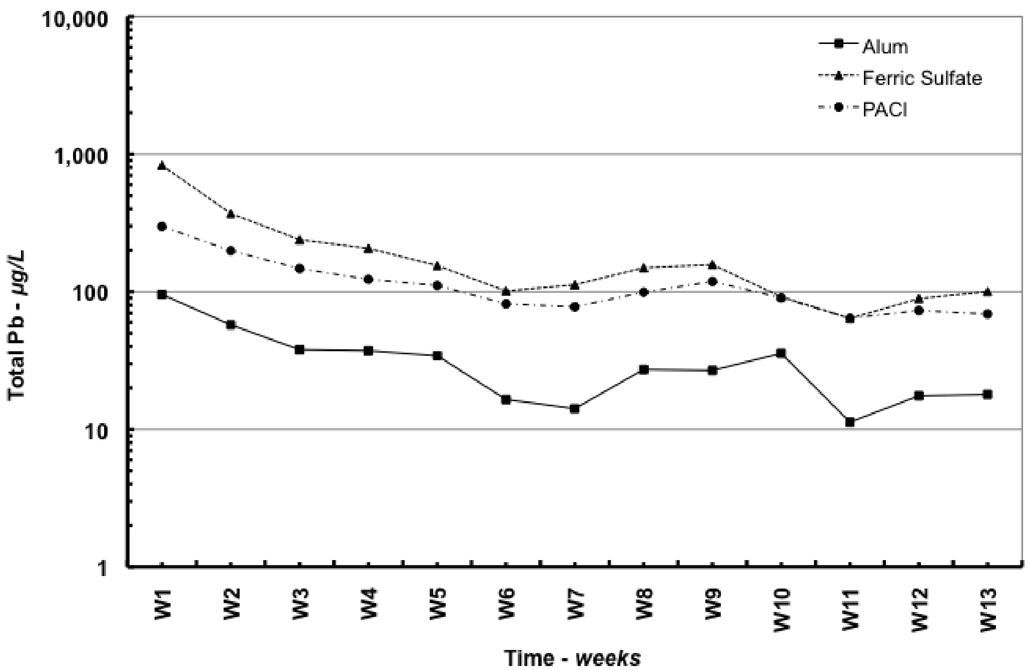


Figure 7.2 Total lead concentrations for the high and low CSMR trials throughout the duration of each study. Data from the two samples per week and triplicate set-ups were averaged to obtain the comparisons in this figure.

(FS = ferric sulfate, PACl = polyaluminum chloride, Alum = aluminum sulfate)

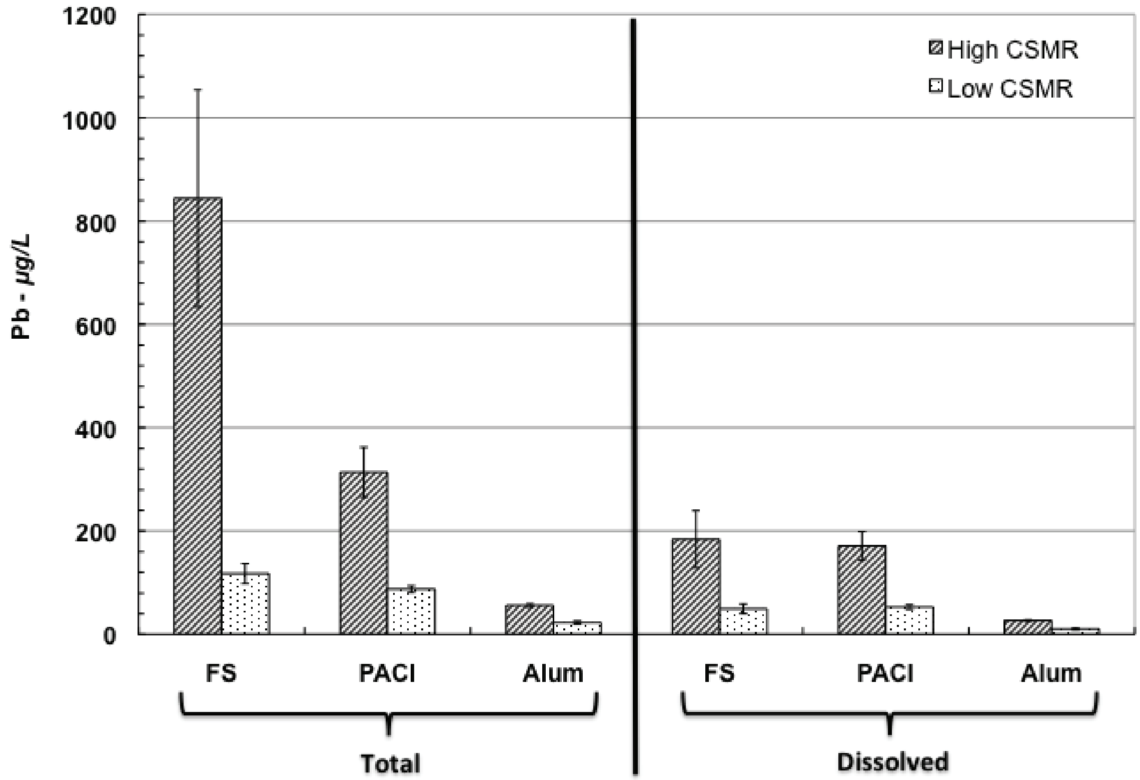
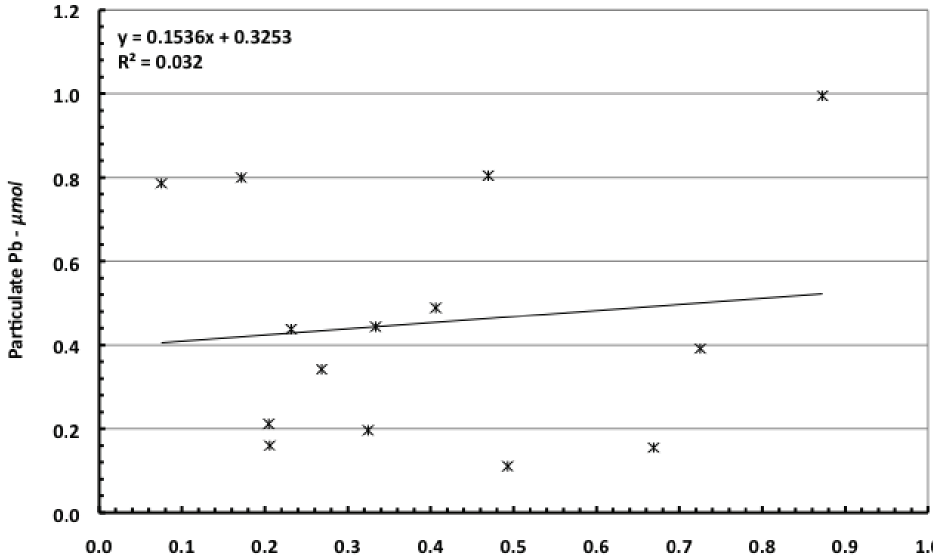


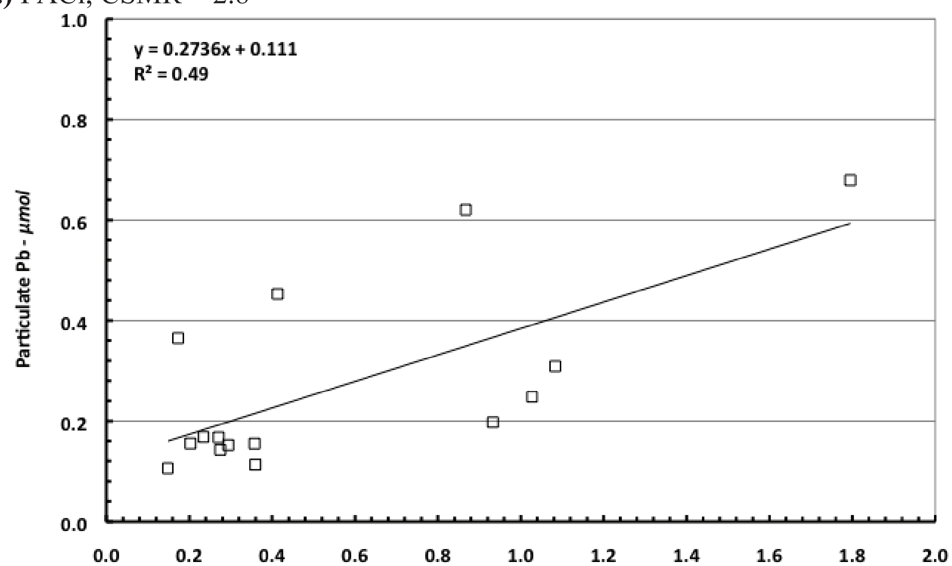
Figure 7.3 Average bulk water total and dissolved lead released (µg/L) for the high CSMR (Weeks 5 through 10) and low CSMR (Weeks 5 through 13) water conditions tested. Data from the triplicate conditions were averaged to obtain the comparisons. The error bars indicate the 95% confidence interval.

(FS = ferric sulfate, PACl = polyaluminum chloride, Alum = aluminum sulfate)

a.) Ferric Sulfate, CSMR = 0.3



b.) PACl, CSMR = 2.8



c.) Alum, CSMR = 0.3

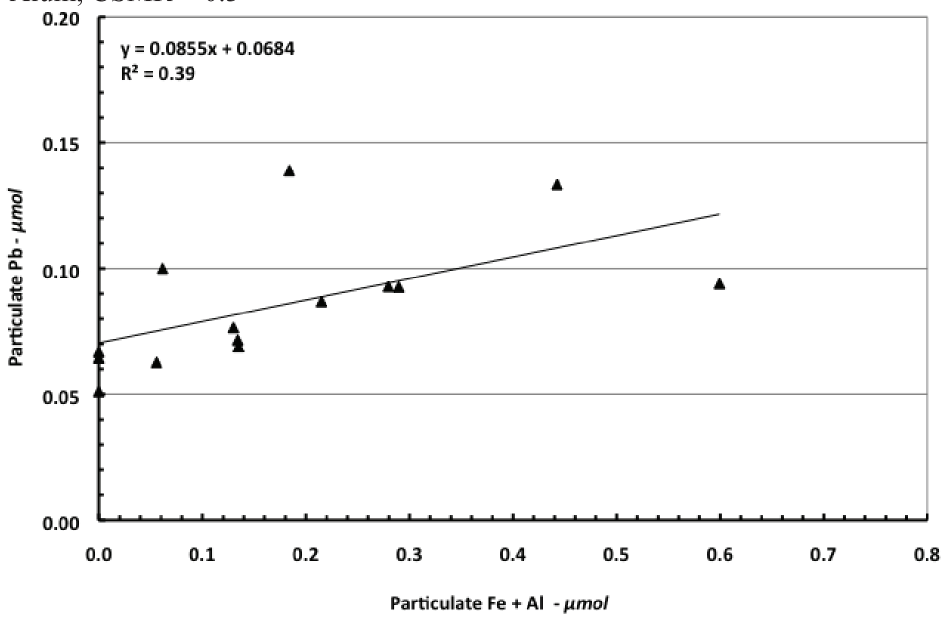


Figure 7.4 Average lead release as a function of iron and aluminum release for during Weeks 3 through 5 for the Low CSMR phase of this study. Data from the triplicate conditions were averaged to obtain the comparisons in this figure.

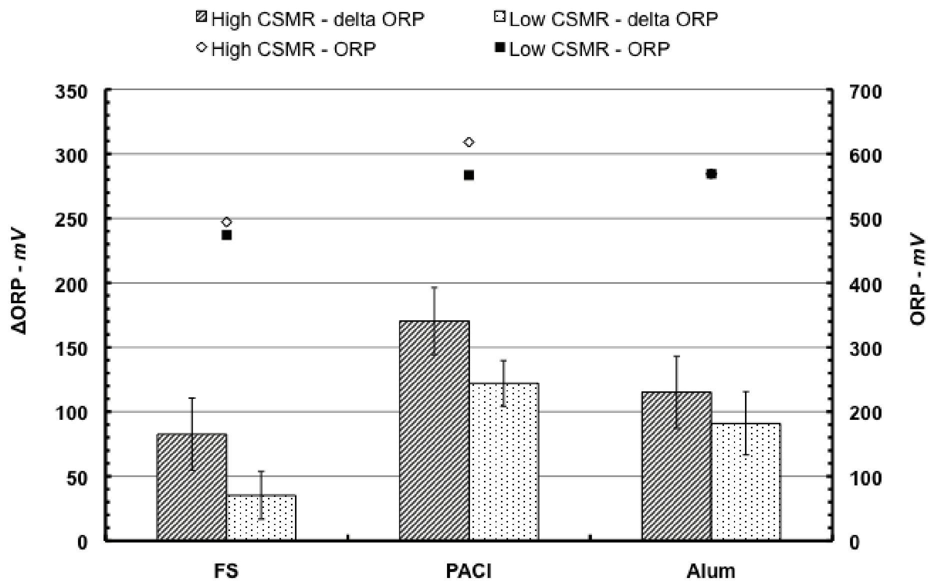


Figure 7.5 Average treated water ORP (mV) and decrease in ORP (mV) during stagnation period for the High CSMR (Weeks 5 through 10) and Low CSMR (Weeks 5 through 13) water conditions tested. Data from triplicate conditions were averaged to obtain the comparisons. The error bars indicate the 95% confidence interval.

(FS = ferric sulfate, PACl = polyaluminum chloride, Alum = aluminum sulfate)

CHAPTER 8 RECOMMENDATIONS

Based on the findings of this research, several opportunities for future research projects were identified that were beyond the scope of this thesis, but merit additional investigation. Future research recommendations are presented for each major research topic presented in this thesis.

8.1. PILOT-PLANT PAIRING

Pilot proving methodology. Although the validation methodology, outlined in Chapter 4, used to pair the pilot plant to the full-scale treatment process was an overall success, there were some post-proving operational and experimental scaling issues related to the differences in mixing regimes between the two scales of treatment. Due to the efficiency of the mechanical mixers in the pilot plant, adding a polymer to the pilot treatment process during cold winter months was not required and, when attempted, produced high particle loading to the filters and filtered water turbidities were unacceptable. This issue was deemed a factor of scale between the two treatment processes and was mitigated by increasing the pilot alum dose to approximately 0.9-mg/L as Al (from 0.7-mg/L as Al) and foregoing the use of a polymer in the pilot treatment process, which brought the filter effluent turbidities to within acceptable levels. In addition, the results of Chapter 5 identified substantial differences between the DBPFP between pilot-plant treated water and FSP treated water using during cold-water operations. The higher DBBfp of the FSP treated water was attributed to the poor mixing performance associated with hydraulic flocculators during full-scale treatment and evidenced increased NOM removal benefits associated with the mechanical mixing capabilities of the pilot plant (Vadasarukkai, 2010).

In light of these post-proving issues, it is recommended that DBPFP and organic matter fractionation techniques be added to the list of response parameters used for pilot-proving trials to provide a more robust means of identifying differences in organic removal performance. It is also recommended that proving trials be repeated during exceptionally challenging treatment events (i.e.; cold-water treatment) to verify that results obtained through pilot-studies will be representative of process changes that will successfully optimize the performance of the FSP.

Pilot proving statistical approach. In future pilot proving studies, it is recommended that the measurement errors for each parameter be considered in order to set achievable and acceptable deviations between pilot and full-scale performance. Contrastingly, the hypothesized mean difference of 0.05-NTU for filter effluent turbidity was not strict enough and a more appropriate performance benchmark for turbidity differences would have been 0.02-NTU in future studies.

8.2. DIRECT-FILTRATION COAGULATION OPTIMIZATION

NOM characterization of FSP versus pilot treated water. The findings of this research exposed significant differences in DBPFP between the FSP and pilot treated water. These differences were primarily attributed the differences in mixing energy applied between the two scales of treatment. In light of these findings, it is recommended that NOM characterization studies be completed on both treated waters, to identify the physical and chemical characteristics of the organic precursors that are increasingly removed by mechanical mixing in the pilot plant and not by the hydraulic flocculators in the FSP.

Mixing optimization studies. Based on the results of Chapter 5, enhanced coagulation is not a viable option for achieving DBP reductions without comprising filtration performance at a this direct filtration facility. Since the differences in DBPFP between the FSP and pilot plant are indicative that upgrading to mechanical mixing in the FSP could yield substantial DBP reductions in FSP treated water, it is recommended that mixing studies are conducted in the pilot plant to identify the optimal mixing intensities required to enhance organic matter removal and, subsequently, reduce DBPs at this facility.

Zeta potential investigation. Since higher coagulant dosages required to meet DBP regulations often lead to unacceptable solids loading in direct filtration facilities, as highlighted by Chapter 5 results, other means of optimizing organic matter removal need to be addressed for such facilities. Recent research has shown that the use of zeta potential, which provides a direct measurement of the surface charge of floc particles, can be used as an effective means of optimizing filtration performance through the addition of a cationic polymer to provide adequate floc formation and increased organic matter removals using reduced coagulant dosages at these facilities (Pernitsky et al., 2011). It is recommended that zeta potential measurements be used as a performance indicator when conducting future optimization studies at this facility.

Pre-chlorination investigation. Chapter 5 presented results that showed substantial differences between DBPFPs achieved during bench-scale and pilot plant experiments simulating the baseline coagulation pH and dosage conditions of the FSP. The key difference between these experiments was the absence of pre-chlorination during bench-scale experiments. If the utility did not depend on pre-chlorination for microbial control in their filters, there is the potential that significant decreases in DBPs could be realized, as eliminating pre-chlorination is an effective way to control DBP levels in finished water (Xie, 2003). It is recommended that a study be conducted to evaluate potential DBP reductions that can be achieved through eliminating pre-chlorination practices in the FSP. As part of this investigation, the option of operating biologically active filters could also be examined for this facility, which may lead to further removal of biodegradable NOM, which are typically recalcitrant to coagulation treatment. If biologically active filters are identified as posing too high of a threat to microbial contamination at this facility, chlorination could be added to filter backwash water to act as a filter aid for microbial control in the filters.

Rapid fractionation techniques for low NOM waters. Although the use of organic size distribution was a useful tool in assessing the relative removals of aromatic organic materials during the coagulation optimization experiments conducted during this thesis project, it would be useful to develop a rapid organic matter characterization procedure to identify the removals of both aromatic and non-aromatic materials during coagulation processes. The organic matter characterization techniques used by Montreuil (2011) for this specific source water required long experimental times, which are not ideal considering the large number of trials required during optimization studies. There have been rapid fractionation techniques used by other researchers (Chow et al., 2004), however, these rapid fractionation techniques would not be successful for characterizing the low organic matter concentrations present in the source water being studied, due to the small volumes of water used.

Identification of surrogate parameters for predicting DBPs for low SUVA waters. This work supports the hypothesis of recent research indicating that DBP predictions based on UV_{254} content in water characterized by low SUVA and low MW NOM fractions are generally weak and, therefore, highlights the importance of hydrophilic organic fractions with low aromaticity as being important DBP precursors in low SUVA waters. It is recommended that a surrogate tool be identified for predicting DBPFP for low SUVA waters to aid in organic matter removal studies and be used in optimizing daily plant operations of such source waters.

8.3. COAGULANT CHANGEOVER CORROSION IMPLICATIONS

Impact of Al and Fe. Results from Chapters 6 and 7 indicate that an important mechanism involved the occurrence of lead release following a coagulant changeover was related to the presence of iron and aluminum concentrations and the adsorption of lead on aluminum and iron oxides. It was also speculated that iron particulates are more detrimental to lead release than aluminum particulates. It is recommended that experiments be designed to specifically study mechanisms associated with Al and Fe particulates contributing to lead release. It is also recommended that the secondary regulatory standards for Al and Fe concentrations following treatment be evaluated based on this hypothesis. In particular, the effects of Fe particulates being released from iron pipes must be further studied in light of practical issues that are being identified by other researchers studying the contribution to lead in drinking water from iron corrosion scales (Deshommes et al., 2010 and McFadden et al., 2011).

Overall contribution of CSMR and Residual Al and Fe. Though the results of Chapters 6 and 7 indicated that CSMRs and residual Al and Fe concentrations following coagulation are significant factors contributing to lead in galvanic settings, the overall contribution of these two factors on lead release was not determined and warrants further research. In particular, it would be interesting to learn if a specific CSMR threshold exists that would mitigate the adsorption of lead on to iron and aluminum oxides under galvanic conditions.

Most importantly, due to the exceptional corrosivity of the ferric-based coagulant in comparison to aluminum-based coagulants, it is recommended that utilities contemplating changing to ferric-based coagulants investigate the potential consequences of adverse effects related to lead release. In general, it is also recommended that utilities that are considering treatment changes examine the potential CSMR and residual Fe and Al concentrations resulting from the change of coagulant and what potential consequences for lead release might be expected from these changes.

Further investigation of corrosion impacts for low alkalinity water. It is believed that the relatively low alkalinity (<20 mg/L as $CaCO_3$) of the treated water conditions investigated in Chapters 6 and 7 likely contributed to the high lead levels presented from each treatment condition studied, since a low buffering capacity is expected to amplify the pH drop at the lead anode under galvanic circumstances (Edwards and Triantafyllidou, 2007) and finished water alkalinities less than 50-mg/L have been shown to trigger serious lead problems in other case studies (Nguyen et al., 2010a; Nguyen et al., 2010c). Although the JDKWSP is currently meeting the lead 90th percentile rule suggested by Health Canada, if a coagulant change is made at this facility down the road or if corrosion ever becomes an issue, is recommended that increased alkalinities be investigated as a means of improved corrosion control for this utility.

Impact of corrosion inhibitors. Though, recently, there has been a reasonable amount of research dedicated to the mechanisms behind CSMR causing lead leaching in water distribution systems, there have been very little recommendations regarding means of mitigating these issues aside from ensuring that the CSMR is maintained below a threshold value of 0.5 through coagulant dose and type control. However, this is not always an option when controlling CSMRs through coagulant dosing is not possible, as would be the case for many direct filtration facilities. For the JDKWSP, the current CSMR of the treated water is approximately 1.0 (0.7-mg/L as Al) and to reduce the CSMR to 0.3, a dosage of 4.4-mg/L as Al is required using alum. Significant increases in coagulant dosages at this facility would lead to significant problems with filtration performance and overall particle removals. Therefore, currently, there is significant potential for lead leaching occurrence resulting from partial lead service line replacements, especially considering the low alkalinity of the treated water. It is recommended that future research consider the type and dosage of corrosion inhibitors that could counter adverse consequences of higher CSMR.

CHAPTER 9 CONCLUSION

9.1. SUMMARY

The overall goal of this thesis was to optimize the removal of organic matter DBP precursors in a direct filtration facility treating surface water with low levels of turbidity, alkalinity and organic matter while ensuring filtration performance is not compromised and significant or harmful effects with respect to lead leaching in the distribution system are not triggered. Four alternate coagulants were evaluated, including ferric sulfate, PACl (MBNS) and ACH (HBNS), against the baseline performance of alum coagulation efforts that are currently practiced at the JDKWSP. Bench-scale and pilot-scale experiments were designed to satisfy the following research objectives:

1. Determine favourable NOM removal coagulation conditions for a low turbidity, low alkalinity, and low organic matter source water.
2. Evaluate particle removal and filtration performance associated with the favourable coagulation conditions determined for NOM removal using a direct filtration pilot plant. If these conditions are significantly different, determine if balanced conditions to meet performance goals can be achieved.
3. Evaluate potential "unintended consequences" of chemical changeovers on finished water quality and distribution systems related to lead release.
4. Develop a framework to assess and optimize coagulation optimization studies to be used by other utilities.

Pilot Proving Experiments. Since direct filtration processes are well known for both sensitivity to solids loading and an inability to be adequately reproduced on a bench-scale

(Eikebrokk et al., 2007 and Pernitsky et al., 2011), pilot-scale testing of optimization options for processes upstream of the direct filtration process is key. Pilot testing essentially closes the uncertainty gap between bench-scale studies and full-scale implementation of research results. Before this research program could begin, it was necessary to carry out a pilot proving process to ensure the results of any research conducted at the pilot-scale would adequately represent process changes that, when implemented at full scale, successfully optimize the performance of the plant. Therefore, several control experiments were carried out to establish that the parallel trains produced statistically equivalent water quality and that the pilot and FSP treatment processes produced comparable effluent quality. The pilot plant proving process included operating the commissioned pilot plant and making necessary adjustments to ensure the aforementioned criteria was achieved. The proving approach applied was based on both the successes and lessons learned from pilot studies carried out in both Ottawa and Windsor, Ontario (Anderson et al., 1993).

Bench-scale NOM Removal Trials. To address concerns associated with DBP regulations, many utilities have adopted or considered the use of alternative chemical coagulants to enhance the removal of NOM prior to disinfection. Previous studies have shown that optimal coagulation conditions for turbidity removal are rarely the same as those for NOM removal; and that, in fact, coagulant demand is usually governed by the concentration of NOM for low turbidity waters (Gregor et al., 1997 and Pernitsky and Edzwald, 2006).

Bench-scale coagulation jar tests were conducted to identify favourable coagulation pH and dosage conditions for NOM removal using alum, ferric sulfate, PACl (MBNS) and ACH (HBNS). These favourable operating conditions were then directly compared to the current coagulation conditions being used in the full-scale treatment plant. NOM removal performance was evaluated using several organic matter response parameters including TOC, DOC, UV_{254}, DBPFP and HPSEC. Particle removal was not evaluated during bench-scale trials since adequate simulation of deep-bed filtration processes was not possible.

Pilot-scale Coagulation Evaluation Trials. Pilot-scale coagulation trials were conducted to provide a snapshot of the feasibility of favourable organic matter removal conditions in terms of filtration performance and to, subsequently, identify favourable pH and dosage conditions that provided acceptable direct filtration performance. Filtration performance indicators included unit filter run volumes, steady-state effluent turbidity and filter ripening volumes. Organic matter removals were also assessed for the coagulation conditions identified as providing favourable filtration performance results.

In addition, a framework was developed for organizing and analyzing the overwhelming amounts of data generated by the various operating conditions and multi-factor response parameters evaluated during pilot testing. This framework used performance indicators to practically score the filtration performance of each coagulant and the corresponding coagulation conditions studied and used graphical heat-mapping techniques to visually assess the results of the performance indicator evaluation and identify optimal operating regions for filtration performance.

Lead Release Consequences. A particular concern associated with coagulation optimization is the potential unintended consequences of a coagulant change on the distribution system, specifically related to lead release from lead pipe and solder materials. Several case studies have concluded that the seemingly innocuous changes induced by changing coagulant types and dosages can result in unexpected high lead concentrations in distribution systems (Dodrill and Edwards, 1995; Nguyen et al., 2010a; Nguyen et al., 2010c). Coagulant changeover case studies have shown that under galvanic conditions, a high CSMR governs lead leaching incidences in distribution systems (Dodrill and Edwards 1995; Edwards and Triantafyllidou 2007; Nguyen et al., 2010a and Nguyen et al., 2010c).

Several bench-scale experiments were conducted to evaluate the potential "unintended consequences" associated with a potential coagulant changeover at the JDKWSP on finished water quality and distribution system corrosion. In Phase 1, bench-scale experiments investigated the role a coagulant change would have in causing a significant effect with respect to lead leaching in drinking water with a high CSMR (> 0.5). The coagulants evaluated in this bench-scale study included alum (CSMR of 0.9), PACl (CSMR of 2.0) and ferric sulfate (CSMR of 0.9) and the two lead bearing plumbing materials examined were lead:tin solder and passivated lead pipe, both in connection with copper pipe. A simple dump and fill protocol was successfully used to screen for significant changes in lead leaching resulting from the coagulation conditions tested.

These experiments lasted for 27 weeks total. The overall results indicated that CSMR was not the controlling factor with respect to lead leaching following the coagulant changeover conditions evaluated in this study. Ferric sulfate was the most corrosive coagulant during this study and residual concentrations of iron and aluminum were identified as the principal lead corrosion contributors.

Next, experiments were designed to determine why ferric sulfate was contributing so much to lead leaching and evaluate if lowering the CSMR of the sulfate based coagulants below the hypothesized lead leaching threshold (<0.5) would mitigate lead leaching and the negative implications of residual Al and Fe. The experimental set-up for Phase utilized lead solder-to-copper coupons. Two distinct experimental trials were conducted to 1. verify the lead release trends reported in Phase 1 using an augmented experimental setup and 2. explore the overall effect on lead release by lowering the CSMR of the sulfate based coagulants to levels below the 0.5 threshold reported to mitigate lead leaching in past studies (Nguyen et al., 2010a, Nguyen et al., 2010c). Trial 1 and 2 experiments lasted 10 and 14 weeks, respectively.

Combining the results from these coagulant changeover experiments provided significant insights into the detrimental effects a coagulant change cause with respect to lead leaching in the distribution system.

9.2. CONCLUSION

Although the overall outlook for reducing DBP precursors through organic matter optimization is not a positive one for the JDKWSP, the overall results of this research project were successful in evaluating coagulation optimization options for this facility and, in the end, did identify several avenues that this facility can pursue to successfully reduce DBP precursors (see Chapter 9). Additionally, this research program provides a successful framework to be used by other utilities as a guide for conducting and analyzing coagulation optimization studies from preliminary bench-scale experiments through to pilot-scale optimization trials.

Pilot Proving Experiments. Modified paired t-tests were successfully applied to establish that equivalent water quality was being produced between the two parallel pilot trains and to verify that the water quality achieved following each treatment phase in the pilot plant mimicked the corresponding treatment process in the FSP. Successive proving trials demonstrated equivalence in multiple water quality parameters throughout the two treatment scales, including pH, UV_{254}, TOC, DOC, alkalinity and turbidity.

The incorporation of an experimental residuals analysis to identify measurement errors for each response parameter used in pilot proving trials was deemed a necessary statistical approach for establishing equivalence between each scale of treatment. Without the incorporation of these experimental errors, using paired t-tests and pre-determined hypothesized mean differences to compare the pilot treatment trains and pilot to FSP processes, respectively, was an approach destined for failure. Although results were generally favourable, these statistical approaches were determined to be too stringent for performance comparison without the experimental errors being taken into account.

Using the measurement error as a basis for train comparison in paired t-tests, correspondence was established between the two pilot trains. For pilot-to-pilot proving trials, the absolute differences between the parallel treatment trains were very minor at each stage of the treatment process and the differences reported were below 0.1-mg/L for TOC and DOC, 0.002-cm^{-1} for UV-absorbance, 0.1 units for pH and 0.1-mg/L for alkalinity. Overall, the magnitudes of the average absolute mean differences reported in this study are comparable or less than those reported by other researchers (Andrews et al., 2005). In addition, percentile ranking was found to be a valuable indicator of filter performance and a useful means of assessing filtration performance between the two pilot treatment trains. Turbidity profiles were found to be similar and reproducible for corresponding filters on each pilot train, which was highlighted by equivalence throughout the ripening phase, steady-state trends and filter breakthrough profiles

Inserting the measurement error limits as the revised mean differences in the paired t-tests was deemed a more reasonable approach for establishing correspondence between the pilot and FSP data and each parameter passed using these revised performance benchmarks at each sample location. Overall, the finished water absolute differences between pilot and full-scale treatment were less than 10% for TOC (<0.15-mg/L) and DOC (<0.08-mg/L), 15% for UV-absorbance (<0.004-cm^{-1}), 0.1 units for pH and 0.02-NTU for steady-state turbidities. The magnitudes of the average absolute mean differences reported in this study are comparable or less than those reported by Andrews et al. (2005).

The pilot proving process demonstrated that the pilot plant has the ability to reproduce water quality outcomes from the FSP and that experimental results from the pilot facility are representative of process changes that will be used to optimize the performance of the FSP. Differences in mixing regimes between the two scales was the main factor of scale identified between the pilot and full-scale facilities and was later highlighted during pilot optimization trials as an opportunity for significant organic DBP precursor reductions in the full scale system. Incorporating the recommendations of Chapter 9, this pilot-proving methodology can be used by utilities to assess the performance of a pilot plant or bench-scale prototype to be used for full-scale optimization studies and provides a systematic process of calibrating prototypes for full-scale optimization.

Bench-scale NOM Removal Trials. Bench-scale NOM removal studies indicated that 30-40% DOC removals were achievable for this source water using favorable coagulation and pH conditions identified through a series of jar test experiments using alum, ferric sulfate, PACl (MBNS) and ACH (HBNS). These removal potentials were 10-20% higher than the organic matter removals currently being achieved during full-scale treatment (~20%). Significantly higher UV_{254} reduction potentials were identified (60-70%), confirming that aromatic organics were more readily removed by coagulation efforts. Although ACH appeared to yield the highest DOC and UV_{254} reduction potentials, on average, these results alone were not convincing. DBPFPs revealed further indication that the high basicity ACH (4-mg/L as Al and pH = 7.0) was the superior performer, achieving the lowest overall THMFP (37% reduction compared to baseline coagulation conditions) and the greatest HAAFP reductions (25% decrease from baseline coagulation conditions). However, HAAFP contributions were not significantly different for any of the enhanced coagulation conditions examined. Compared to the other coagulants tested, the high basicity ACH also yielded the highest potential coagulation pH which provided hope for significant cost savings related to pH adjusting chemicals if these conditions were feasible at the pilot scale.

Organic size distribution results indicated that high MW, aromatic organic constituents were readily removed by coagulants, whereas low MW, aromatic structures were not at all affected by the coagulation conditions tested. The overall nature of NOM in this source water before (SUVA=2.6) and after (SUVA=1.5) coagulation was accurately predicted by SUVA interpretation guidelines developed by Edzwald and Van Benschoten (1990) (Pernitsky and Edzwald, 2006). The overall effectiveness of coagulation processes was also correctly described by these guidelines, as the maximum organic matter removals identified during bench-scale coagulation studies were low (30-40%), as predicted when treating low SUVA (<3) source waters. The overall results of this study were consistent with the findings of other researchers who observed high MW, aromatic organic structures are preferentially removed by coagulation processes, whereas low MW, non-aromatic structures are generally recalcitrant to removal by coagulation (Liang and Singer, 2003; Pernitsky and Edzwald, 2006; Ates et al., 2007).

The weak UV_{254}-DBPFP correlations identified during bench-scale studies support the hypotheses of recent researchers finding that organic structures other than aromatics also contribute to the production of DBPs and that DBP predictions based on UV_{254} content in water characterized by low SUVA and low MW NOM fractions are generally weak. These results highlight the importance of low MW hydrophilic organic fractions with low aromaticity as being important DBP precursors in low SUVA waters.

Pilot-scale Coagulation Evaluation Trials. Results from pilot testing demonstrated that favourable conditions identified for increased potential NOM removals during bench-scale testing were not consistent with optimal filtered water particle removal. Consistent with the findings of other researchers, the pilot-scale results show that for low turbidity waters, the optimization of coagulant dosages to remove even very low NOM concentrations can severely compromise the filtration performance of direct filtration processes.

When tested at the pilot scale, the favourable organic matter removal coagulation conditions resulted in low UFRV, high effluent filter turbidities and unacceptably long filter ripening times. This poor filtration performance was attributed to the higher than acceptable solids loadings to the filters resulting from the high coagulant dosages required to achieve desirable organic matter removals and the limited treatment barriers present in a direct filtration process (i.e.; lack of a clarification stage prior to filtration). Since coagulant overdosing was evidently not an option, coagulation pH was identified as the most important operating parameter for direct filtration processes. Low coagulation pHs are desirable to increase the charge density of NOM and, therefore, reduce the amount of coagulant required for charge neutralization, and encourage the formation of soluble NOM-aluminum complexes due to the increased concentrations of highly charged metal species at lower pH values.

Favourable filtration conditions were identified using both PACl and ACH (1.0-1.15-mg/L as Al and pH of 5.8), producing short filter run volumes, low effluent turbidities and short filter ripening times. However, the coagulation conditions that were required to obtain favourable filtration performance using ACH (1.1-mg/L and pH = 5.8) did not provide any organic matter removal benefits when compared to the performance of the control pilot train operating using the same day alum baseline operating conditions as the FSP plant (0.9-mg/L, pH = 5.5).

Perhaps the most important conclusion of this thesis, significant differences were identified between the DBPFP of pilot plant treated water and FSP treated water operating using coagulation conditions deemed "equivalent" during pilot proving studies. The higher DBBfp of FSP treated water demonstrated the poor mixing performance associated with hydraulic flocculators during full-scale treatment and highlighted significant potentials for increased NOM removal benefits associated with mechanical mixing capabilities of the pilot plant.

Finally, a generic framework was developed to organize and evaluate the large quantities of filtration data generated during pilot studies using PIs and graphical heat-mapping techniques. PI scores were used to assess coagulation operating conditions based the combined performance of UFRV, steady-state turbidity values and FRV. Heat-mapping techniques were successfully used to verify that PI scores were accurate representations of the data and also to visually simplify and identify favourable operating regions for each filter response parameter. As was true with the pilot proving methodology, these techniques are directly applicable to other facilities and can be used by other utilities to interpret and assess optimization results.

Overall, results from pilot-testing demonstrated that the optimal conditions for NOM control from bench-scale testing are not consistent with optimal filtration performance at a direct filtration facility. Although bench-scale investigations offer a great starting point to evaluate relative performance conditions for organic matter removal, pilot-scale research is vital to effectively evaluating particle removals and filtration performance for direct filtration facilities. Considering the overall results from all of the coagulant conditions study during pilot testing, it appears that the coagulation pH and dosage window for optimal filtration performance is very tight for this source water and treatment process. The results are also indicative that enhanced coagulation treatment to reduce DBP precursors is not feasible at this facility without comprising filtration performance. These findings also stress the importance of investigating coagulation as a multi-objective optimization process in which both turbidity and organic removal are important output parameters. Finally, this work emphasizes the need for further research of ways to reduce DBP precursors in direct filtration facilities without compromising filtration performance (see Chapter 9 recommendations).

Lead Release Consequences. Both practical case studies and laboratory-based studies have demonstrated that a high CSMR induces high galvanic currents and governs leach-leaching incidences in lead-to-copper connections in distribution systems following coagulant changeovers (Dodrill and Edwards, 1995; Edwards et al., 1999; Edwards and Triantafyllidou, 2007, Nguyen et al., 2010). However, CSMR was not the primary catalyst for lead leaching following coagulant changeovers for the conditions evaluated in this study. Residual concentrations of iron and aluminum remaining following coagulation were found to be the principal contributors.

Analysis of the results revealed positive correlations between residual total iron and aluminum concentrations following coagulation and total lead concentrations following stagnation for each coagulant tested. The positive correlations shown between particulate iron and aluminum and particulate lead concentrations following stagnation confirmed that the adsorption of lead to iron and aluminum oxides is a viable hypothesis for lead release. Despite the variable CSMR levels tested, both above and below the 0.5 CSMR threshold cited for lead leaching, ferric sulfate consistently yielded the highest lead levels following stagnation, due to high residual iron concentrations remaining following coagulation. In addition, overall results suggest that iron particulates may play a more important role in lead release than aluminum particulates. CSMR effects were secondary to the corrosive effects of particulate iron, as evidenced by PACl (CSMR of 2.0 and 2.8) being consistently more corrosive that alum (CSMR 0.9 and 0.3), regardless of residual aluminum concentrations following coagulation.

Consistent with the findings in this study, past and recent investigations involving both field testing and pipe loop experiments have concluded that particulate lead concentrations are positively correlated with particulate iron concentrations (Hulsmann, 1990; Deshommes et al., 2010 and Triantafyllidou and Edwards, 2011). It is hypothesized that adsorption of lead on iron particles is a dominant cause of lead release in systems where particulate iron is entering the distribution system (Hulsmann, 1990; Deshommes et al., 2010).

In general, the results of this research underline the importance of ensuring corrosive factors are not unintentionally introduced by seemingly innocuous changes such as coagulant dosage adjustments or changeovers. Although suggested by other researchers, problems occurring following coagulant changeovers are not always controlled by reducing CSMRs below the 0.5 threshold (Nguyen et al., 2010a and Nguyen et al., 2010c). If a utility is planning a coagulant changeover, the effects of coagulation residuals on distribution water quality should be experimentally verified before such changes are implemented at full-scale.

Since the coagulation optimization studies conducted as part of this research project found that a coagulant changeover would not lead to additional DBP precursor reductions at the JDKWSP, distribution system lead leaching issues are not a pressing concern for this facility. Of the three coagulants tested, alum was the least corrosive chemical at CSMR levels both above and below the lead-leaching threshold. If an increase in alum dose is identified as a feasible optimization change at this facility in future studies, the lower CSMR induced would not be a potential corrosion concern, however, residual Al concentrations should be minimized to ensure corrosion issues are not unintentionally triggered. That being said, the current CSMR of the treated water at the JDKWSP is approximately 1.0 (0.7-mg/L as Al) and to reduce the CSMR to less than 0.5 requires significantly higher dosages of alum. As shown in Chapter 5, significant increases in coagulant dosages at this facility would lead to significant problems with filtration performance and overall particle removals. Therefore, currently, there is significant potential for lead leaching occurrence resulting from partial lead service line replacements, especially considering the low alkalinity of the treated water.

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APPENDIX A – Chapter 4 Raw and Supplemental Data

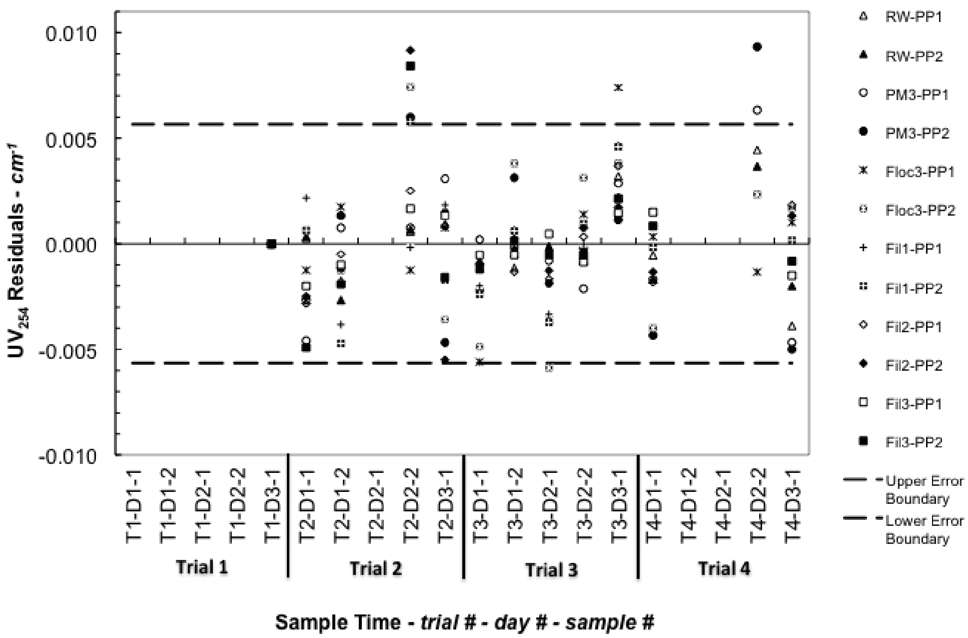

Figure A1. **UV_{254} error analysis distribution for the four the pilot-to-pilot proving trials completed. Upper and lower boundary lines represent two standard deviations of the residual population mean.**

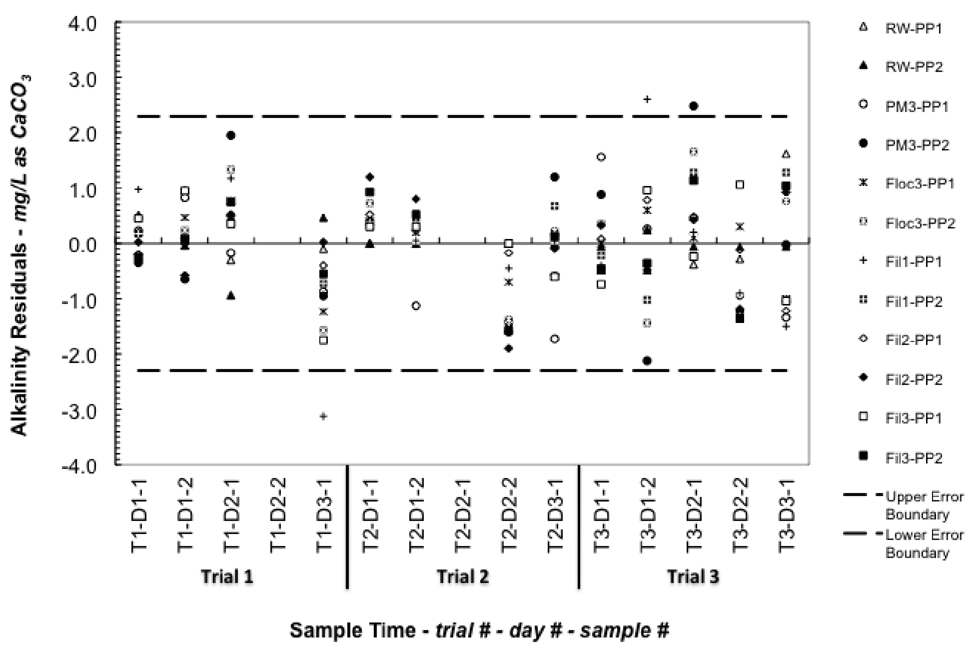

Figure A2. **Alkalinity error analysis distribution for the pilot-to-pilot proving trials completed (no alkalinity data was collected during trial 4). Upper and lower boundary lines represent two standard deviations of the residual population mea**

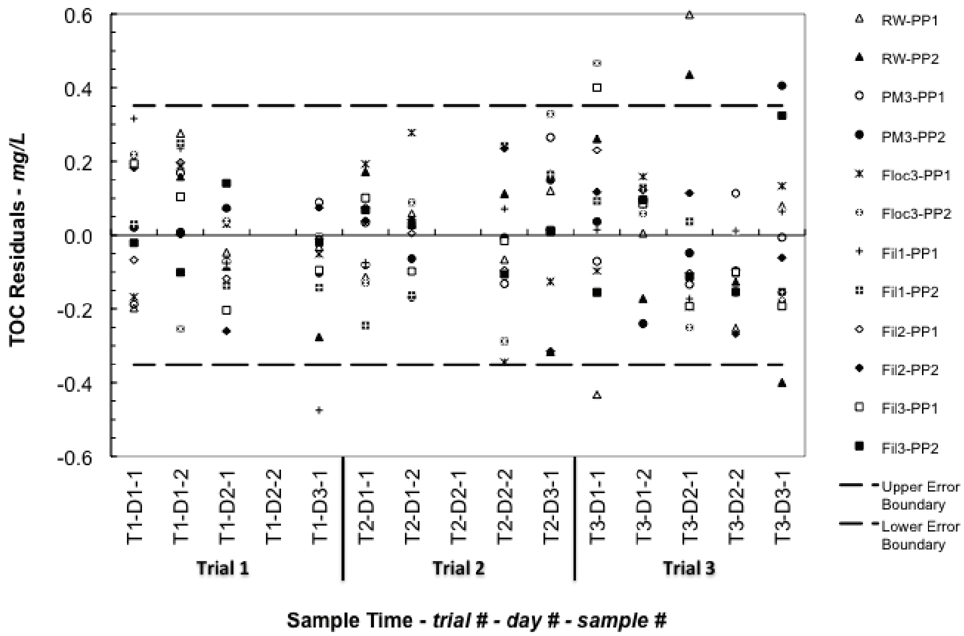

Figure A3. TOC error analysis distribution for the pilot-to-pilot proving trials completed (no TOC data was collected during trial 4). Upper and lower boundary lines represent two standard deviations of the residual population mean.

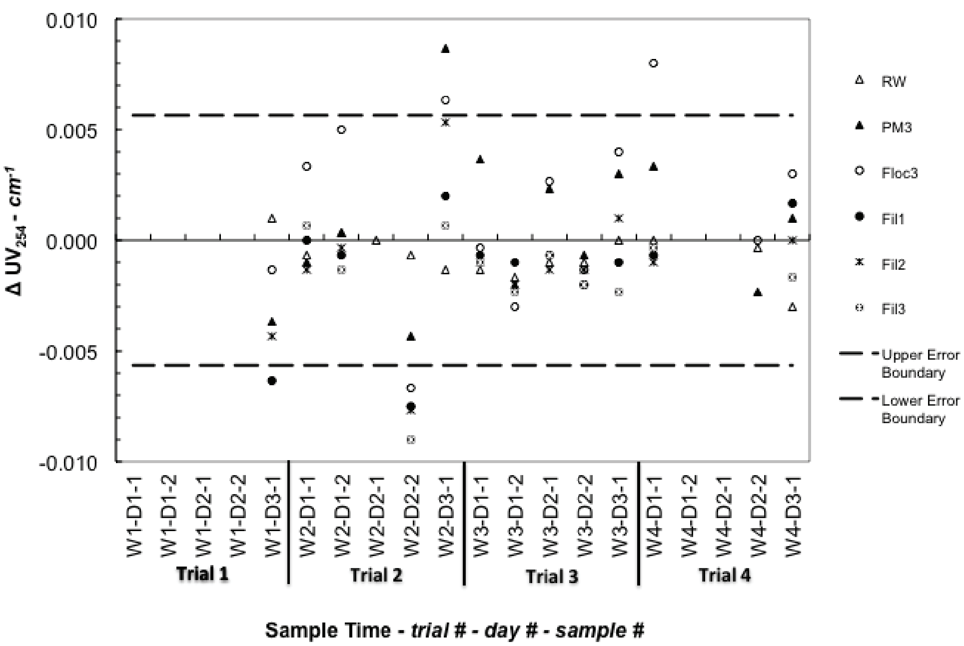

Figure A4. UV_{254} absolute difference between Pilot Train 1 (PP1) and Pilot Train 2 PP2 for the pilot-to-pilot proving trials completed. Upper and lower boundary lines represent two standard deviations of the residual population mean.

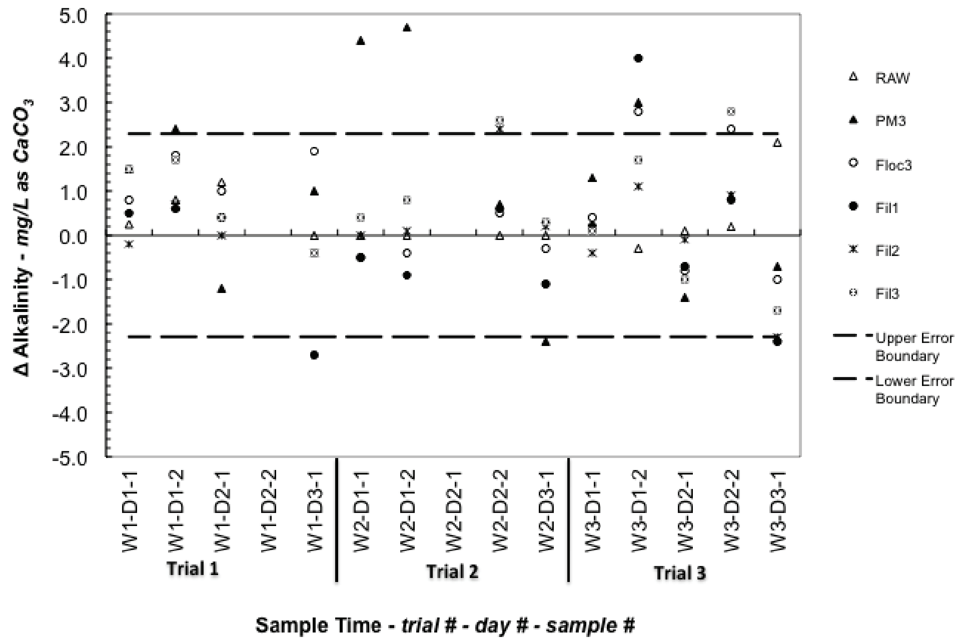

Figure A5. Alkalinity absolute difference between Pilot Train 1 (PP1) and Pilot Train 2 PP2 for the pilot-to-pilot proving trials completed (no alkalinity data was collected during trial 4). Upper and lower boundary lines represent two standard deviations of the residual population mean.

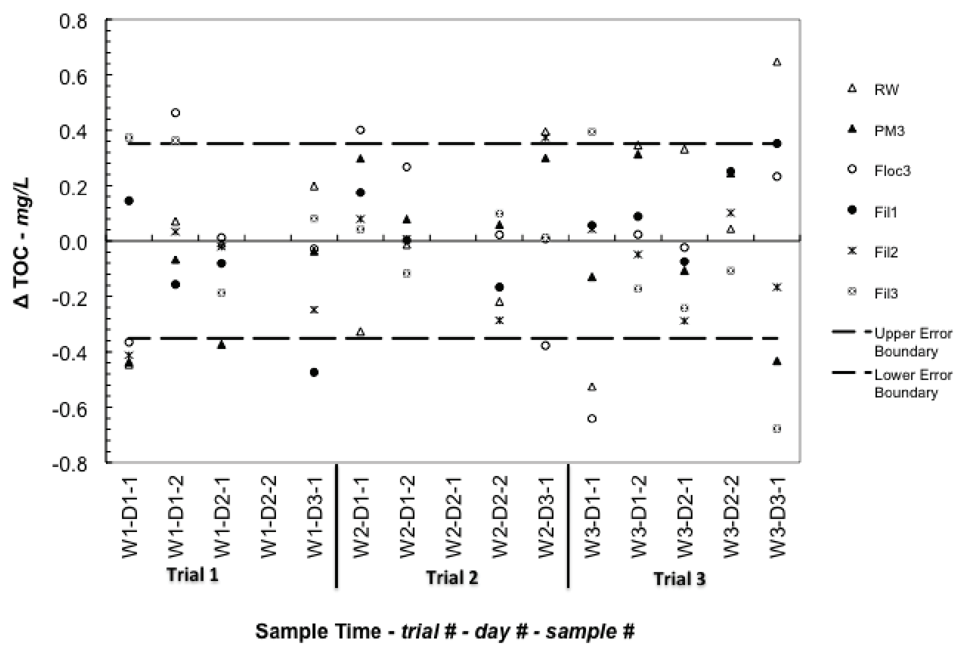

Figure A6. TOC absolute difference between Pilot Train 1 (PP1) and Pilot Train 2 PP2 for the pilot-to-pilot proving trials completed (no TOC data was collected during trial 4). Upper and lower boundary lines represent two standard deviations of the residual population mean.

Table A1. Pilot-to-Pilot Proving Raw Data, Error Analysis and Absolute Differences

pH

		PP1	PP2	ε_{PP1}	ε_{PP2}	PP1-PP2	95% T-test		Residuals T-test			
RW	T1-D1-1	4.88	4.87	0.17	0.24	0.01					$PP1x_{avg}$	4.71
	T1-D1-2	4.93	4.91	0.22	0.28	0.02					$PP2x_{avg}$	4.63
	T1-D2-1	4.80	4.76	0.09	0.13	0.04						
	T1-D2-2											
	T1-D3-1	4.24	3.98	-0.47	-0.65	0.26						
RW	T2-D1-1	4.96	4.73	0.09	-0.08	0.23					$PP1x_{avg}$	4.87
	T2-D1-2	4.91	4.89	0.04	0.08	0.02					$PP2x_{avg}$	4.81
	T2-D2-1											
	T2-D2-2	4.77	4.77	-0.10	-0.04	0.00						
	T2-D3-1	4.84	4.84	-0.03	0.03	-0.01						
RW	T3-D1-1	4.95	4.89	0.08	0.05	0.06					$PP1x_{avg}$	4.86
	T3-D1-2	5.02	4.98	0.15	0.14	0.04					$PP2x_{avg}$	4.84
	T3-D2-1	4.78	4.75	-0.08	-0.09	0.03						
	T3-D2-2	4.84	4.82	-0.03	-0.02	0.02	d_{bar}	0.03				
	T3-D3-1	4.73	4.75	-0.13	-0.09	-0.02	std error	0.022				
RW	T4-D1-1	4.76	4.79	-0.02	-0.02	-0.04	t	1.746			$PP1x_{avg}$	4.77
	T4-D1-2	4.84	4.80	0.07	-0.01	0.04	s*t	0.038	d_{bar}	0.03	$PP2x_{avg}$	4.81
	T4-D2-1						β_1	-0.005	β_1	-0.260		
	T4-D2-2	4.70	4.76	-0.07	-0.05	-0.06	β_2	0.070	β_2	0.260		
	T4-D3-1	4.80	4.89	0.02	0.08	-0.09	P/F	True	P/F	True		
PM3	W1-D1-1	5.51	5.24	0.16	0.03	0.27					$PP1x_{avg}$	5.35
	W1-D1-2	5.54	5.34	0.19	0.13	0.20					$PP2x_{avg}$	5.21
	W1-D2-1	5.36	5.31	0.01	0.10	0.05						
	W1-D2-2											
	W1-D3-1	4.98	4.94	-0.37	-0.27	0.04						
PM3	W2-D1-1	5.47	5.31	0.05	-0.06	0.16					$PP1x_{avg}$	5.42
	W2-D1-2	5.54	5.49	0.13	0.12	0.05					$PP2x_{avg}$	5.37
	W2-D2-1											
	W2-D2-2	5.30	5.24	-0.11	-0.13	0.06						
	W2-D3-1	5.35	5.44	-0.06	0.07	-0.09						
PM3	W3-D1-1	5.62	5.57	0.07	0.09	0.05					$PP1x_{avg}$	5.56
	W3-D1-2	5.71	5.50	0.15	0.02	0.21					$PP2x_{avg}$	5.49
	W3-D2-1	5.45	5.44	-0.10	-0.05	0.02						
	W3-D2-2	5.56	5.45	0.00	-0.03	0.11	d_{bar}	0.07				
	W3-D3-1	5.44	5.46	-0.12	-0.02	-0.02	std error	0.025				
PM3	W4-D1-1	5.45	5.40	-0.02	-0.05	0.04	t	1.746			$PP1x_{avg}$	5.47
	W4-D1-2	5.39	5.52	-0.08	0.07	-0.13	s*t	0.043	d_{bar}	0.07	$PP2x_{avg}$	5.45
	W4-D2-1						β_1	0.026	β_1	-0.260		
	W4-D2-2	5.49	5.36	0.02	-0.09	0.13	β_2	0.113	β_2	0.260		
	W4-D3-1	5.56	5.52	0.09	0.07	0.04	P/F	False	P/F	True		
Floc3	W1-D1-1	5.43	5.20	0.08	0.03	0.22					$PP1x_{avg}$	5.35
	W1-D1-2	5.49	5.30	0.14	0.12	0.19					$PP2x_{avg}$	5.18
	W1-D2-1	5.41	5.20	0.06	0.02	0.21						
	W1-D2-2											
	W1-D3-1	5.06	5.00	-0.29	-0.17	0.06						
Floc3	W2-D1-1	5.31	5.36	-0.03	0.00	-0.05					$PP1x_{avg}$	5.34
	W2-D1-2	5.49	5.48	0.15	0.13	0.00					$PP2x_{avg}$	5.36
	W2-D2-1											
	W2-D2-2	5.29	5.25	-0.05	-0.11	0.04						
	W2-D3-1	5.28	5.33	-0.06	-0.02	-0.05						
Floc3	W3-D1-1	5.59	5.48	0.09	0.00	0.11					$PP1x_{avg}$	5.50
	W3-D1-2	5.67	5.57	0.17	0.09	0.10					$PP2x_{avg}$	5.48
	W3-D2-1	5.42	5.48	-0.08	0.00	-0.07						
	W3-D2-2	5.44	5.41	-0.06	-0.07	0.03	d_{bar}	0.03				
	W3-D3-1	5.39	5.46	-0.11	-0.02	-0.07	std error	0.025				
Floc3	W4-D1-1	5.38	5.47	-0.05	0.00	-0.09	t	1.746			$PP1x_{avg}$	5.43
	W4-D1-2	5.51	5.47	0.08	0.00	0.04	s*t	0.044	d_{bar}	0.03	$PP2x_{avg}$	5.47
	W4-D2-1						β_1	-0.012	β_1	-0.260		
	W4-D2-2	5.42	5.44	-0.01	-0.04	-0.01	β_2	0.077	β_2	0.260		
	W4-D3-1	5.41	5.51	-0.02	0.04	-0.11	P/F	True	P/F	True		
Fil1	W1-D1-1	5.39	5.21	0.09	0.05	0.19					$PP1x_{avg}$	5.31
	W1-D1-2	5.51	5.31	0.20	0.16	0.19					$PP2x_{avg}$	5.15
	W1-D2-1	5.40	5.21	0.09	0.06	0.18						
	W1-D2-2											
	W1-D3-1	4.92	4.88	-0.38	-0.28	0.05						
Fil1	W2-D1-1	5.37	5.29	0.00	-0.02	0.08					$PP1x_{avg}$	5.37
	W2-D1-2	5.47	5.42	0.10	0.11	0.05					$PP2x_{avg}$	5.31
	W2-D2-1											
	W2-D2-2	5.42	5.27	0.05	-0.04	0.15						
	W2-D3-1	5.22	5.27	-0.15	-0.04	-0.05						
Fil1	W3-D1-1	5.51	5.48	0.02	0.02	0.03					$PP1x_{avg}$	5.49
	W3-D1-2	5.72	5.61	0.23	0.15	0.12					$PP2x_{avg}$	5.46
	W3-D2-1	5.39	5.44	-0.10	-0.02	-0.05						
	W3-D2-2	5.48	5.39	-0.01	-0.07	0.09	d_{bar}	0.05				
	W3-D3-1	5.34	5.39	-0.15	-0.07	-0.05	std error	0.025				
Fil1	W4-D1-1	5.29	5.37	-0.08	-0.08	-0.08	t	1.753			$PP1x_{avg}$	5.37
	W4-D1-2	5.44	5.49	0.08	0.04	-0.04	s*t	0.044	d_{bar}	0.05	$PP2x_{avg}$	5.45
	W4-D2-1						β_1	0.002	β_1	-0.260		
	W4-D2-2						β_2	0.091	β_2	0.260		
	W4-D3-1	5.37	5.48	0.00	0.03	-0.11	P/F	False	P/F	True		
Fil2	W1-D1-1	5.40	5.20	0.13	0.09	0.20					$PP1x_{avg}$	5.28
	W1-D1-2	5.53	5.31	0.25	0.20	0.21					$PP2x_{avg}$	5.11
	W1-D2-1	5.28	5.18	0.00	0.06	0.11						
	W1-D2-2											
	W1-D3-1	4.90	4.76	-0.38	-0.35	0.14						
Fil2	W2-D1-1	5.33	5.32	-0.02	0.00	0.01					$PP1x_{avg}$	5.36
	W2-D1-2	5.49	5.45	0.14	0.14	0.04					$PP2x_{avg}$	5.32
	W2-D2-1											
	W2-D2-2	5.36	5.21	0.01	-0.11	0.15						
	W2-D3-1	5.23	5.28	-0.12	-0.03	-0.05						
Fil2	W3-D1-1	5.51	5.45	0.05	0.01	0.06					$PP1x_{avg}$	5.46
	W3-D1-2	5.70	5.58	0.25	0.14	0.12					$PP2x_{avg}$	5.44
	W3-D2-1	5.31	5.44	-0.15	0.00	-0.13						
	W3-D2-2	5.45	5.38	-0.01	-0.07	0.07	d_{bar}	0.05				
	W3-D3-1	5.32	5.36	-0.14	-0.08	-0.05	std error	0.027				
Fil2	W4-D1-1	5.39	5.45	0.00	0.00	-0.06	t	1.753			$PP1x_{avg}$	5.39
	W4-D1-2	5.45	5.46	0.06	0.01	0.00	s*t	0.047	d_{bar}	0.05	$PP2x_{avg}$	5.45
	W4-D2-1						β_1	-0.002	β_1	-0.260		
	W4-D2-2						β_2	0.092	β_2	0.260		
	W4-D3-1	5.33	5.44	-0.06	-0.01	-0.11	P/F	True	P/F	True		

UV-254 (cm^{-1})

		PP1	PP2	ε_{PP1}	ε_{PP2}	PP1-PP2	95% T-test		Residuals T-test			
RW	T1-D1-1										PP1xavg	0.101
	T1-D1-2										PP2xavg	0.100
	T1-D2-1											
	T1-D2-2											
	T1-D3-1	0.101	0.100	0.000	0.000	0.001						
RW	T2-D1-1	0.105	0.105	0.000	0.000	-0.001					PP1xavg	0.104
	T2-D1-2	0.103	0.102	-0.002	-0.003	0.000					PP2xavg	0.105
	T2-D2-1											
	T2-D2-2	0.105	0.106	0.001	0.001	-0.001						
	T2-D3-1	0.105	0.107	0.001	0.002	-0.001						
RW	T3-D1-1	0.104	0.105	-0.001	-0.001	-0.001					PP1xavg	0.105
	T3-D1-2	0.104	0.106	-0.001	0.000	-0.002					PP2xavg	0.106
	T3-D2-1	0.105	0.106	0.000	0.000	-0.001						
	T3-D2-2	0.104	0.105	-0.001	-0.001	-0.001	d_{bar}	-0.001				
	T3-D3-1	0.108	0.108	0.003	0.002	0.000	std error	0.000				
RW	T4-D1-1	0.106	0.106	-0.001	-0.002	0.000	t	1.782			PP1xavg	0.107
	T4-D1-2						s*t	0.000	d_{bar}	-0.001	PP2xavg	0.108
	T4-D2-1						β_1	-0.001	β_1	-0.006		
	T4-D2-2	0.111	0.111	0.004	0.004	0.000	β_2	0.000	β_2	0.006		
	T4-D3-1	0.103	0.106	-0.004	-0.002	-0.003	P/F	False	P/F	True		
PM3	W1-D1-1										PP1xavg	0.041
	W1-D1-2										PP2xavg	0.045
	W1-D2-1											
	W1-D2-2											
	W1-D3-1	0.041	0.045	0.000	0.000	-0.004						
PM3	W2-D1-1	0.044	0.045	-0.005	-0.003	-0.001					PP1xavg	0.048
	W2-D1-2	0.049	0.049	0.001	0.001	0.000					PP2xavg	0.047
	W2-D2-1											
	W2-D2-2	0.049	0.053	0.001	0.006	-0.004						
	W2-D3-1	0.051	0.043	0.003	-0.005	0.009						
PM3	W3-D1-1	0.042	0.038	0.000	-0.002	0.004					PP1xavg	0.042
	W3-D1-2	0.042	0.044	0.000	0.003	-0.002					PP2xavg	0.041
	W3-D2-1	0.041	0.039	-0.001	-0.002	0.002						
	W3-D2-2	0.040	0.040	-0.002	0.000	-0.001	d_{bar}	0.001				
	W3-D3-1	0.045	0.042	0.003	0.001	0.003	std error	0.001				
PM3	W4-D1-1	0.040	0.037	-0.002	-0.004	0.003	t	1.782			PP1xavg	0.042
	W4-D1-2						s*t	0.001	d_{bar}	0.001	PP2xavg	0.041
	W4-D2-1						β_1	0.000	β_1	-0.006		
	W4-D2-2	0.048	0.050	0.006	0.009	-0.002	β_2	0.002	β_2	0.006		
	W4-D3-1	0.037	0.036	-0.005	-0.005	0.001	P/F	True	P/F	True		
Floc3	W1-D1-1										PP1xavg	0.043
	W1-D1-2										PP2xavg	0.045
	W1-D2-1											
	W1-D2-2											
	W1-D3-1	0.043	0.045	0.000	0.000	-0.001						
Floc3	W2-D1-1	0.048	0.044	-0.001	-0.003	0.003					PP1xavg	0.049
	W2-D1-2	0.051	0.046	0.002	-0.001	0.005					PP2xavg	0.047
	W2-D2-1											
	W2-D2-2	0.048	0.054	-0.001	0.007	-0.007						
	W2-D3-1	0.050	0.043	0.001	-0.004	0.006						
Floc3	W3-D1-1	0.039	0.039	-0.006	-0.005	0.000					PP1xavg	0.045
	W3-D1-2	0.045	0.048	0.000	0.004	-0.003					PP2xavg	0.044
	W3-D2-1	0.041	0.038	-0.004	-0.006	0.003						
	W3-D2-2	0.046	0.047	0.001	0.003	-0.001	d_{bar}	0.002				
	W3-D3-1	0.052	0.048	0.007	0.004	0.004	std error	0.001				
Floc3	W4-D1-1	0.046	0.038	0.000	-0.004	0.008	t	1.782			PP1xavg	0.045
	W4-D1-2						s*t	0.002	d_{bar}	0.002	PP2xavg	0.042
	W4-D2-1						β_1	-0.001	β_1	-0.006		
	W4-D2-2	0.044	0.044	-0.001	0.002	0.000	β_2	0.004	β_2	0.006		
	W4-D3-1	0.046	0.043	0.001	0.002	0.003	P/F	True	P/F	True		
Fil1	W1-D1-1										PP1xavg	0.047
	W1-D1-2										PP2xavg	0.053
	W1-D2-1											
	W1-D2-2											
	W1-D3-1	0.047	0.053	0.000	0.000	-0.006						
Fil1	W2-D1-1	0.049	0.049	0.002	0.001	0.000					PP1xavg	0.047
	W2-D1-2	0.043	0.044	-0.004	-0.005	-0.001					PP2xavg	0.049
	W2-D2-1											
	W2-D2-2	0.047	0.055	0.000	0.006	-0.007						
	W2-D3-1	0.049	0.047	0.002	-0.002	0.002						
Fil1	W3-D1-1	0.043	0.044	-0.002	-0.002	-0.001					PP1xavg	0.045
	W3-D1-2	0.046	0.047	0.001	0.001	-0.001					PP2xavg	0.046
	W3-D2-1	0.042	0.042	-0.003	-0.004	-0.001						
	W3-D2-2	0.045	0.047	0.000	0.001	-0.002	d_{bar}	-0.001				
	W3-D3-1	0.050	0.051	0.005	0.005	-0.001	std error	0.001				
Fil1	W4-D1-1	0.044	0.045	-0.001	0.000	-0.001	t	1.796			PP1xavg	0.046
	W4-D1-2						s*t	0.001	d_{bar}	-0.001	PP2xavg	0.045
	W4-D2-1						β_1	-0.003	β_1	-0.006		
	W4-D2-2						β_2	0.000	β_2	0.006		
	W4-D3-1	0.047	0.045	0.001	0.000	0.002	P/F	True	P/F	True		
Fil2	W1-D1-1										PP1xavg	0.045
	W1-D1-2										PP2xavg	0.049
	W1-D2-1											
	W1-D2-2											
	W1-D3-1	0.045	0.049	0.000	0.000	-0.004						
Fil2	W2-D1-1	0.042	0.044	-0.003	-0.003	-0.001					PP1xavg	0.045
	W2-D1-2	0.045	0.045	-0.001	-0.001	0.000					PP2xavg	0.046
	W2-D2-1											
	W2-D2-2	0.048	0.055	0.003	0.009	-0.008						
	W2-D3-1	0.046	0.041	0.001	-0.006	0.005						
Fil2	W3-D1-1	0.043	0.044	-0.001	-0.001	-0.001					PP1xavg	0.044
	W3-D1-2	0.043	0.045	-0.001	0.000	-0.002					PP2xavg	0.045
	W3-D2-1	0.043	0.044	-0.002	-0.001	-0.001						
	W3-D2-2	0.045	0.046	0.000	0.001	-0.001	d_{bar}	-0.001				
	W3-D3-1	0.048	0.047	0.004	0.002	0.001	std error	0.001				
Fil2	W4-D1-1	0.042	0.043	-0.002	-0.001	-0.001	t	1.796			PP1xavg	0.044
	W4-D1-2						s*t	0.002	d_{bar}	-0.001	PP2xavg	0.045
	W4-D2-1						β_1	-0.003	β_1	-0.006		
	W4-D2-2						β_2	0.000	β_2	0.006		
	W4-D3-1	0.046	0.046	0.002	0.001	0.000	P/F	True	P/F	True		

Alkalinity (as CaCO3)

		PP1	PP2	ε_{PP1}	ε_{PP2}	PP1-PP2	95% T-test		Residuals T-test			
RW	T1-D1-1	0.3	0.1	0.2	0.0	0.3					PP1xavg	0.2
	T1-D1-2	0.3	0.0	0.2	0.0	0.3					PP2xavg	0.0
	T1-D2-1	0.0	0.0	-0.2	0.0	0.0						
	T1-D2-2											
	T1-D3-1	0.0	0.0	-0.2	0.0	0.0						
RW	T2-D1-1	0.0	0.0	0.0	0.0	0.0					PP1xavg	0.0
	T2-D1-2	0.0	0.0	0.0	0.0	0.0					PP2xavg	0.0
	T2-D2-1											
	T2-D2-2	0.0	0.0	0.0	0.0	0.0						
	T2-D3-1	0.0	0.0	0.0	0.0	0.0						
RW	T3-D1-1	0.0	0.0	-0.5	-0.1	0.0					PP1xavg	0.5
	T3-D1-2	0.0	0.3	-0.5	0.2	-0.3					PP2xavg	0.1
	T3-D2-1	0.1	0.0	-0.4	-0.1	0.1						
	T3-D2-2	0.2	0.0	-0.3	-0.1	0.2	d_{bar}	0.20				
	T3-D3-1	2.1	0.0	1.6	-0.1	2.1	std error	0.163				
RW	T4-D1-1						t	1.782			PP1xavg	
	T4-D1-2						s*t	0.291	d_{bar}	0.20	PP2xavg	
	T4-D2-1						β_1	-0.087	β_1	-2.287		
	T4-D2-2						β_2	0.495	β_2	2.287		
	T4-D3-1						P/F	True	P/F	True		
PM3	W1-D1-1	5.9	4.4	0.2	-0.4	1.5					PP1xavg	5.7
	W1-D1-2	6.5	4.1	0.8	-0.7	2.4					PP2xavg	4.8
	W1-D2-1	5.5	6.7	-0.2	2.0	-1.2						
	W1-D2-2											
	W1-D3-1	4.8	3.8	-0.9	-1.0	1.0						
PM3	W2-D1-1	10.1	5.7	4.3	0.4	4.4					PP1xavg	5.8
	W2-D1-2	4.7		-1.1							PP2xavg	5.3
	W2-D2-1											
	W2-D2-2	4.4	3.7	-1.4	-1.6	0.7						
	W2-D3-1	4.1	6.5	-1.7	1.2	-2.4						
PM3	W3-D1-1	9.3	8.0	1.6	0.9	1.3					PP1xavg	7.7
	W3-D1-2	8.0	5.0	0.3	-2.1	3.0					PP2xavg	7.1
	W3-D2-1	8.2	9.6	0.5	2.5	-1.4						
	W3-D2-2	6.8	5.9	-0.9	-1.2	0.9	d_{bar}	0.79				
	W3-D3-1	6.4	7.1	-1.3	0.0	-0.7	std error	0.567				
PM3	W4-D1-1						t	1.796			PP1xavg	#DIV/0!
	W4-D1-2						s*t	1.019	d_{bar}	0.79	PP2xavg	#DIV/0!
	W4-D2-1						β_1	-0.227	β_1	-2.287		
	W4-D2-2						β_2	1.811	β_2	2.287		
	W4-D3-1						P/F	True	P/F	True		
Floc3	W1-D1-1										PP1xavg	5.7
	W1-D1-2	6.2	4.4	0.5	0.2	1.8					PP2xavg	4.2
	W1-D2-1	6.5	5.5	0.8	1.3	1.0						
	W1-D2-2											
	W1-D3-1	4.5	2.6	-1.2	-1.6	1.9						
Floc3	W2-D1-1	5.1	5.6	0.4	0.7	-0.5					PP1xavg	4.7
	W2-D1-2	4.9	5.3	0.2	0.4	-0.4					PP2xavg	4.9
	W2-D2-1											
	W2-D2-2	4.0	3.5	-0.7	-1.4	0.5						
	W2-D3-1	4.8	5.1	0.1	0.2	-0.3						
Floc3	W3-D1-1	7.4	7.0	0.0	0.4	0.4					PP1xavg	7.4
	W3-D1-2	8.0	5.2	0.6	-1.4	2.8					PP2xavg	6.6
	W3-D2-1	7.5	8.3	0.1	1.7	-0.8						
	W3-D2-2	7.7	5.3	0.3	-1.3	2.4	d_{bar}	0.65				
	W3-D3-1	6.4	7.4	-1.0	0.8	-1.0	std error	0.379				
Floc3	W4-D1-1						t	1.796			PP1xavg	#DIV/0!
	W4-D1-2						s*t	0.680	d_{bar}	0.65	PP2xavg	#DIV/0!
	W4-D2-1						β_1	-0.030	β_1	-2.287		
	W4-D2-2						β_2	1.330	β_2	2.287		
	W4-D3-1						P/F	True	P/F	True		
Fil1	W1-D1-1	5.8	5.3	1.0	0.2	0.5					PP1xavg	4.8
	W1-D1-2	5.8	5.2	1.0	0.1	0.6					PP2xavg	5.1
	W1-D2-1	6.0	5.6	1.2	0.5	0.4						
	W1-D2-2											
	W1-D3-1	1.7	4.4	-3.1	-0.7	-2.7						
Fil1	W2-D1-1	4.7	5.2	0.4	0.4	-0.5					PP1xavg	4.4
	W2-D1-2	4.4	5.3	0.0	0.5	-0.9					PP2xavg	4.8
	W2-D2-1											
	W2-D2-2	3.9	3.3	-0.5	-1.5	0.6						
	W2-D3-1	4.4	5.5	0.0	0.7	-1.1						
Fil1	W3-D1-1	6.5	6.3	-0.4	-0.2	0.2					PP1xavg	6.9
	W3-D1-2	9.5	5.5	2.6	-1.0	4.0					PP2xavg	6.5
	W3-D2-1	7.1	7.8	0.2	1.3	-0.7						
	W3-D2-2	6.0	5.2	-0.9	-1.3	0.8	d_{bar}	-0.09				
	W3-D3-1	5.4	7.8	-1.5	1.3	-2.4	std error	0.463				
Fil1	W4-D1-1						t	1.782			PP1xavg	#DIV/0!
	W4-D1-2						s*t	0.826	d_{bar}	-0.09	PP2xavg	#DIV/0!
	W4-D2-1						β_1	-0.918	β_1	-2.287		
	W4-D2-2						β_2	0.734	β_2	2.287		
	W4-D3-1						P/F	True	P/F	True		
Fil2	W1-D1-1	5.4	5.6	-0.2	0.0	-0.2					PP1xavg	5.6
	W1-D1-2	5.7	5.0	0.1	-0.6	0.7					PP2xavg	5.6
	W1-D2-1	6.1	6.1	0.5	0.5	0.0						
	W1-D2-2			-5.6	-5.6							
	W1-D3-1	5.2	5.6	-0.4	0.0	-0.4						
Fil2	W2-D1-1	5.5	5.5	0.5	1.2	0.0					PP1xavg	5.0
	W2-D1-2	5.2	5.1	0.2	0.8	0.1					PP2xavg	4.3
	W2-D2-1											
	W2-D2-2	4.8	2.4	-0.2	-1.9	2.4						
	W2-D3-1	4.4	4.2	-0.6	-0.1	0.2						
Fil2	W3-D1-1	6.8	7.2	0.1	0.3	-0.4					PP1xavg	6.7
	W3-D1-2	7.5	6.4	0.8	-0.5	1.1					PP2xavg	6.9
	W3-D2-1	7.2	7.3	0.5	0.4	-0.1						
	W3-D2-2	6.6	5.7	-0.1	-1.2	0.9	d_{bar}	0.15				
	W3-D3-1	5.5	7.8	-1.2	0.9	-2.3	std error	0.296				
Fil2	W4-D1-1						t	1.782			PP1xavg	#DIV/0!
	W4-D1-2						s*t	0.528	d_{bar}	0.15	PP2xavg	#DIV/0!
	W4-D2-1						β_1	-0.374	β_1	-2.287		
	W4-D2-2						β_2	0.681	β_2	2.287		
	W4-D3-1						P/F	True	P/F	True		

TOC (mg/L)

		PP1	PP2	ε_{PP1}	ε_{PP2}	PP1-PP2	95% T-test		Residuals T-test			
RW	T1-D1-1	2.48	2.926	-0.198	0.203	-0.446					PP1xavg	2.678
	T1-D1-2	2.954	2.882	0.276	0.159	0.072					PP2xavg	2.724
	T1-D2-1	2.631	2.639	-0.047	-0.084	-0.008						
	T1-D2-2											
	T1-D3-1	2.646	2.45	-0.032	-0.277	0.199						
RW	T2-D1-1	2.623	2.95	-0.114	0.172	-0.327					PP1xavg	2.737
	T2-D1-2	2.796	2.809	0.059	0.031	-0.013					PP2xavg	2.778
	T2-D2-1											
	T2-D2-2	2.671	2.89	-0.066	0.112	-0.219						
	T2-D3-1	2.857	2.46	0.120	-0.316	0.395						
RW	T3-D1-1	2.382	2.907	-0.432	0.262	-0.525					PP1xavg	2.814
	T3-D1-2	2.82	2.474	0.006	-0.171	0.346					PP2xavg	2.645
	T3-D2-1	3.413	3.081	0.599	0.436	0.332						
	T3-D2-2	2.563	2.519	-0.251	-0.126	0.044	d_{bar}	0.10				
	T3-D3-1	2.894	2.25	0.080	-0.399	0.648	std error	0.089				
RW	T4-D1-1	3.377	2.82	0.220	-0.022	0.557	t	1.753			PP1xavg	3.157
	T4-D1-2	3.169	2.641	0.012	-0.201	0.528	s*t	0.156	d_{bar}	0.102	PP2xavg	2.842
	T4-D2-1						β_1	-0.054	β_1	-0.351		
	T4-D2-2	2.924	2.874	-0.233	0.032	0.050	β_2	0.258	β_2	0.351		
	T4-D3-1		3.03		0.190		P/F	True	P/F	True		
PM3	W1-D1-1	2.445	2.882	-0.188	0.021	-0.437					PP1xavg	2.633
	W1-D1-2	2.802	2.869	0.170	0.008	-0.067					PP2xavg	2.861
	W1-D2-1	2.561	2.934	-0.071	0.073	-0.373						
	W1-D2-2											
	W1-D3-1	2.722	2.76	0.090	-0.103	-0.036						
PM3	W2-D1-1	2.694	2.396	0.034	-0.079	0.298					PP1xavg	2.660
	W2-D1-2	2.492	2.412	-0.168	-0.063	0.080					PP2xavg	2.476
	W2-D2-1											
	W2-D2-2	2.528	2.469	-0.132	-0.006	0.059						
	W2-D3-1	2.925	2.63	0.265	0.150	0.300						
PM3	W3-D1-1	2.724	2.853	-0.071	0.036	-0.129					PP1xavg	2.795
	W3-D1-2	2.891	2.577	0.096	-0.240	0.314					PP2xavg	2.817
	W3-D2-1	2.661	2.768	-0.134	-0.049	-0.107						
	W3-D2-2	2.908	2.663	0.113	-0.154	0.245	d_{bar}	0.03				
	W3-D3-1	2.789	3.22	-0.006	0.405	-0.433	std error	0.076				
PM3	W4-D1-1						t	1.761			PP1xavg	3.014
	W4-D1-2	2.877	2.648	-0.137	-0.093	0.229	s*t	0.135	d_{bar}	0.032	PP2xavg	2.741
	W4-D2-1						β_1	-0.102	β_1	-0.351		
	W4-D2-2		2.963		0.222		β_2	0.167	β_2	0.351		
	W4-D3-1	3.15	2.61	0.137	-0.129	0.538	P/F	True	P/F	True		
Floc3	W1-D1-1	2.546	2.911	-0.167	0.218	-0.365					PP1xavg	2.713
	W1-D1-2	2.902	2.439	0.189	-0.254	0.463					PP2xavg	2.693
	W1-D2-1	2.743	2.731	0.030	0.038	0.012						
	W1-D2-2											
	W1-D3-1	2.662	2.69	-0.051	-0.003	-0.028						
Floc3	W2-D1-1	3.006	2.605	0.193	-0.130	0.401					PP1xavg	2.813
	W2-D1-2	3.091	2.824	0.278	0.089	0.267					PP2xavg	2.735
	W2-D2-1											
	W2-D2-2	2.469	2.447	-0.344	-0.288	0.022						
	W2-D3-1	2.687	3.06	-0.126	0.329	-0.377						
Floc3	W3-D1-1	2.423	3.064	-0.097	0.466	-0.641					PP1xavg	2.520
	W3-D1-2	2.679	2.656	0.159	0.058	0.023					PP2xavg	2.598
	W3-D2-1	2.325	2.348	-0.195	-0.250	-0.023						
	W3-D2-2		2.502		-0.096		d_{bar}	0.00				
	W3-D3-1	2.653	2.42	0.133	-0.178	0.233	std error	0.095				
Floc3	W4-D1-1		2.779		0.046		t	1.796			PP1xavg	2.867
	W4-D1-2		2.687		-0.046		s*t	0.170	d_{bar}	-0.001	PP2xavg	2.733
	W4-D2-1						β_1	-0.172	β_1	-0.351		
	W4-D2-2	2.867		0.000			β_2	0.169	β_2	0.351		
	W4-D3-1						P/F	True	P/F	True		
Fil1	W1-D1-1	2.461	2.316	0.316	0.029	0.145					PP1xavg	2.145
	W1-D1-2	2.38	2.536	0.235	0.250	-0.156					PP2xavg	2.287
	W1-D2-1	2.069	2.15	-0.076	-0.137	-0.081						
	W1-D2-2											
	W1-D3-1	1.67	2.14	-0.475	-0.143	-0.474						
Fil1	W2-D1-1	2.189	2.014	-0.075	-0.245	0.175					PP1xavg	2.264
	W2-D1-2	2.099	2.096	-0.165	-0.163	0.003					PP2xavg	2.259
	W2-D2-1											
	W2-D2-2	2.335	2.501	0.071	0.243	-0.166						
	W2-D3-1	2.431	2.42	0.168	0.165	0.008						
Fil1	W3-D1-1	2.21	2.153	0.015	0.093	0.057					PP1xavg	2.195
	W3-D1-2	2.277	2.188	0.082	0.128	0.089					PP2xavg	2.060
	W3-D2-1	2.023	2.097	-0.172	0.037	-0.074						
	W3-D2-2	2.207	1.956	0.012	-0.104	0.251	d_{bar}	0.01				
	W3-D3-1	2.259	1.91	0.064	-0.153	0.352	std error	0.059				
Fil1	W4-D1-1						t	1.782			PP1xavg	2.292
	W4-D1-2						s*t	0.105	d_{bar}	0.010	PP2xavg	#DIV/0!
	W4-D2-1						β_1	-0.095	β_1	-0.351		
	W4-D2-2						β_2	0.114	β_2	0.351		
	W4-D3-1	2.292		0.000			P/F	True	P/F	True		
Fil2	W1-D1-1	2.069	2.481	-0.067	0.183	-0.412					PP1xavg	2.136
	W1-D1-2	2.333	2.3	0.197	0.002	0.033					PP2xavg	2.298
	W1-D2-1	2.018	2.038	-0.118	-0.260	-0.020						
	W1-D2-2											
	W1-D3-1	2.125	2.37	-0.011	0.075	-0.248						
Fil2	W2-D1-1	2.378	2.298	0.075	0.039	0.080					PP1xavg	2.303
	W2-D1-2	2.308	2.301	0.005	0.042	0.007					PP2xavg	2.259
	W2-D2-1											
	W2-D2-2	2.208	2.494	-0.095	0.235	-0.286						
	W2-D3-1	2.317	1.94	0.014	-0.315	0.373						
Fil2	W3-D1-1	2.351	2.309	0.230	0.117	0.042					PP1xavg	2.121
	W3-D1-2	2.243	2.291	0.122	0.099	-0.048					PP2xavg	2.192
	W3-D2-1	2.018	2.306	-0.103	0.114	-0.288						
	W3-D2-2	2.026	1.924	-0.095	-0.268	0.102	d_{bar}	-0.06				
	W3-D3-1	1.965	2.13	-0.156	-0.061	-0.166	std error	0.058				
Fil2	W4-D1-1		2.195		0.030		t	1.782			PP1xavg	2.087
	W4-D1-2		2.135		-0.030		s*t	0.104	d_{bar}	-0.064	PP2xavg	2.165
	W4-D2-1						β_1	-0.168	β_1	-0.351		
	W4-D2-2						β_2	0.040	β_2	0.351		
	W4-D3-1	2.087		0.000			P/F	True	P/F	True		

DOC (mg/L)

		PP1	PP2	ε_{PP1}	ε_{PP2}	95% T-test		Residuals T-test		PP1-PP2		
RW	T1-D1-1	2.93	2.69	0.146	0.007					0.236	PP1xavg	2.781
	T1-D1-2	2.97	2.93	0.188	0.250					0.035	PP2xavg	2.683
	T1-D2-1	2.61	2.59	-0.168	-0.093					0.023		
	T1-D2-2											
	T1-D3-1	2.62	2.52	-0.166	-0.164					0.096		
RW	T2-D1-1	2.87	2.78	0.217	0.173					0.087	PP1xavg	2.649
	T2-D1-2	2.58	2.50	-0.065	-0.106					0.084	PP2xavg	2.606
	T2-D2-1											
	T2-D2-2	2.75	2.63	0.103	0.027					0.120		
	T2-D3-1	2.39	2.51	-0.256	-0.094					-0.119		
RW	T3-D1-1	2.96	3.07	0.091	0.408					-0.113	PP1xavg	2.869
	T3-D1-2	2.91	2.94	0.039	0.275					-0.032	PP2xavg	2.665
	T3-D2-1	2.73	2.28	-0.139	-0.387					0.452		
	T3-D2-2	2.80	2.34	-0.065	-0.321	d_{bar}	0.00			0.460		
	T3-D3-1	2.94	2.69	0.072	0.025	std error	0.054			0.251		
RW	T4-D1-1		2.73		-0.064	t	1.753				PP1xavg	3.155
	T4-D1-2		2.66		-0.135	s*t	0.095	d_{bar}	0.124		PP2xavg	2.795
	T4-D2-1					β_1	-0.095	β_1	-0.325			
	T4-D2-2	3.16	2.99	0.000	0.199	β_2	0.095	β_2	0.325	0.161		
	T4-D3-1					P/F	True	P/F	True			
PM3	W1-D1-1	2.14	2.01	0.191	-0.006					0.132	PP1xavg	1.953
	W1-D1-2	1.88	2.24	-0.077	0.222					-0.364	PP2xavg	2.018
	W1-D2-1	1.84	1.84	-0.111	-0.183					0.007		
	W1-D2-2											
	W1-D3-1	1.95	1.99	-0.003	-0.033					-0.035		
PM3	W2-D1-1	1.80	2.09	-0.205	-0.038					-0.292	PP1xavg	2.005
	W2-D1-2	2.04	2.48	0.033	0.348					-0.440	PP2xavg	2.130
	W2-D2-1											
	W2-D2-2	1.86	1.98	-0.150	-0.147					-0.128		
	W2-D3-1	2.33	1.97	0.321	-0.163					0.359		
PM3	W3-D1-1	2.42	2.09	0.231	0.053					0.333	PP1xavg	2.193
	W3-D1-2	2.18	2.36	-0.011	0.323					-0.179	PP2xavg	2.038
	W3-D2-1	2.30	1.82	0.110	-0.222					0.487		
	W3-D2-2	1.82	1.90	-0.371	-0.139	d_{bar}	0.00			-0.077		
	W3-D3-1	2.24	2.02	0.043	-0.014	std error	0.044			0.212		
PM3	W4-D1-1	1.97	2.20	-0.089	-0.020	t	1.753			-0.233	PP1xavg	2.060
	W4-D1-2		2.10		-0.120	s*t	0.077	d_{bar}	-0.029		PP2xavg	2.224
	W4-D2-1					β_1	-0.077	β_1	-0.325			
	W4-D2-2	2.15	2.37	0.089	0.141	β_2	0.077	β_2	0.325	-0.216		
	W4-D3-1					P/F	True	P/F	True			
Floc3	W1-D1-1	1.94	2.13	-0.103	0.299					-0.184	PP1xavg	2.047
	W1-D1-2	2.11	1.83	0.067	-0.003					0.288	PP2xavg	1.829
	W1-D2-1	2.08	1.99	0.028	0.161					0.085		
	W1-D2-2											
	W1-D3-1	2.06	1.37	0.009	-0.457					0.684		
Floc3	W2-D1-1	2.18	1.89	0.107	-0.074					0.285	PP1xavg	2.071
	W2-D1-2	1.95	1.99	-0.117	0.023					-0.036	PP2xavg	1.967
	W2-D2-1											
	W2-D2-2	2.15	2.13	0.075	0.160					0.019		
	W2-D3-1	2.01	1.86	-0.064	-0.108					0.148		
Floc3	W3-D1-1	2.26	2.07	0.166	-0.062					0.192	PP1xavg	2.096
	W3-D1-2	2.07	2.03	-0.031	-0.104					0.037	PP2xavg	2.132
	W3-D2-1	1.88	2.60	-0.219	0.472					-0.727		
	W3-D2-2	2.09	1.85	-0.002	-0.283	d_{bar}	0.00			0.245		
	W3-D3-1	2.18	2.11	0.084	-0.025	std error	0.055			0.073		
Floc3	W4-D1-1	1.98	2.08	-0.233	0.020	t	1.753			-0.105	PP1xavg	2.211
	W4-D1-2	2.47		0.263		s*t	0.096	d_{bar}	0.068		PP2xavg	2.063
	W4-D2-1					β_1	-0.096	β_1	-0.325			
	W4-D2-2	2.18	2.17	-0.030	0.108	β_2	0.096	β_2	0.325	0.010		
	W4-D3-1		1.94		-0.128	P/F	True	P/F	True			
Fil1	W1-D1-1	1.78	2.12	-0.151	-0.028					-0.337	PP1xavg	1.930
	W1-D1-2	1.79	2.33	-0.141	0.184					-0.539	PP2xavg	2.144
	W1-D2-1	2.01	2.02	0.082	-0.124					-0.008		
	W1-D2-2											
	W1-D3-1	2.14	2.11	0.211	-0.033					0.030		
Fil1	W2-D1-1	1.93	2.13	-0.161	0.099					-0.196	PP1xavg	2.092
	W2-D1-2	2.24	2.15	0.144	0.122					0.086	PP2xavg	2.028
	W2-D2-1											
	W2-D2-2	1.98	1.95	-0.115	-0.074					0.023		
	W2-D3-1	2.22	1.88	0.131	-0.146					0.341		
Fil1	W3-D1-1	2.13	1.96	-0.018	-0.231					0.166	PP1xavg	2.145
	W3-D1-2	2.39	2.11	0.248	-0.079					0.280	PP2xavg	2.192
	W3-D2-1	2.21	2.45	0.069	0.260					-0.238		
	W3-D2-2	1.97	2.08	-0.180	-0.111	d_{bar}	0.00			-0.116		
	W3-D3-1	2.03	2.35	-0.117	0.160	std error	0.041			-0.324		
Fil1	W4-D1-1	2.15	2.14	-0.058		t	1.782			0.010	PP1xavg	2.207
	W4-D1-2	2.26		0.057		s*t	0.074	d_{bar}	-0.059		PP2xavg	2.139
	W4-D2-1					β_1	-0.074	β_1	-0.325			
	W4-D2-2					β_2	0.074	β_2	0.325			
	W4-D3-1					P/F	True	P/F	True			
Fil2	W1-D1-1	2.03	2.16	0.059	0.103					-0.136	PP1xavg	1.969
	W1-D1-2	2.09	2.21	0.124	0.152					-0.121	PP2xavg	2.061
	W1-D2-1	1.74	1.80	-0.230	-0.262					-0.060		
	W1-D2-2											
	W1-D3-1	2.02	2.07	0.047	0.006					-0.052		
Fil2	W2-D1-1	2.10	1.90	0.031	-0.131					0.194	PP1xavg	2.067
	W2-D1-2	2.13	1.95	0.059	-0.083					0.174	PP2xavg	2.034
	W2-D2-1											
	W2-D2-2	1.90	2.22	-0.164	0.184					-0.315		
	W2-D3-1	2.14	2.06	0.075	0.030					0.077		
Fil2	W3-D1-1	2.06	1.99	0.008	0.042					0.068	PP1xavg	2.051
	W3-D1-2	2.07	1.94	0.022	-0.009					0.133	PP2xavg	1.949
	W3-D2-1	2.05	2.24	-0.001	0.292					-0.191		
	W3-D2-2	2.13	1.84	0.075	-0.105	d_{bar}	0.00			0.282		
	W3-D3-1	1.95	1.73	-0.106	-0.220	std error	0.044			0.216		
Fil2	W4-D1-1	1.95	2.27	-0.194		t	1.782				PP1xavg	2.139
	W4-D1-2	2.33		0.194		s*t	0.079	d_{bar}	0.021		PP2xavg	2.270
	W4-D2-1					β_1	-0.079	β_1	-0.325			
	W4-D2-2					β_2	0.079	β_2	0.325			
	W4-D3-1					P/F	True	P/F	True			

Fil3	W1-D1-1	5.42	5.22	0.14	0.08	0.19				
	W1-D1-2	5.50	5.31	0.23	0.16	0.19				
	W1-D2-1	5.15	5.09	-0.12	-0.06	0.06				
	W1-D2-2									
	W1-D3-1	5.03	4.97	-0.25	-0.18	0.06				
Fil3	W2-D1-1	5.39	5.33	0.05	0.02	0.07				
	W2-D1-2	5.43	5.42	0.09	0.12	0.01				
	W2-D2-1									
	W2-D2-2	5.40	5.22	0.06	-0.08	0.18				
	W2-D3-1	5.14	5.25	-0.20	-0.05	-0.12				
Fil3	W3-D1-1	5.57	5.48	0.12	0.03	0.09				
	W3-D1-2	5.62	5.54	0.17	0.09	0.08				
	W3-D2-1	5.33	5.37	-0.13	-0.08	-0.05				
	W3-D2-2	5.49	5.43	0.03	-0.02	0.06	d_{bar}	0.04		
	W3-D3-1	5.27	5.42	-0.19	-0.03	-0.15	std error	0.026		
Fil3	W4-D1-1	5.35	5.40	-0.03	-0.01	-0.05	t	1.753		
	W4-D1-2	5.47	5.47	0.09	0.06	0.00	s*t	0.045	d_{bar}	0.04
	W4-D2-1						β_1	-0.008	β_1	-0.260
	W4-D2-2						β_2	0.081	β_2	0.260
	W4-D3-1	5.32	5.37	-0.06	-0.05	-0.05	**P/F**	**True**	**P/F**	**True**

Sample											
W1-D1-1	*PP1* x_{avg}	5.27									
W1-D1-2	*PP2* x_{avg}	5.15									
W1-D2-1											
W1-D2-2											
W1-D3-1			0.044	0.049	0.000	0.000	-0.005				
W2-D1-1	*PP1* x_{avg}	5.34	0.043	0.042	-0.002	-0.005	0.001				
W2-D1-2	*PP2* x_{avg}	5.31	0.044	0.045	-0.001	-0.002	-0.001				
W2-D2-1											
W2-D2-2			0.046	0.055	0.002	0.008	-0.009				
W2-D3-1			0.046	0.045	0.001	-0.002	0.001				
W3-D1-1	*PP1* x_{avg}	5.46	0.041	0.042	-0.001	-0.001	-0.001				
W3-D1-2	*PP2* x_{avg}	5.45	0.041	0.043	-0.001	0.000	-0.002				
W3-D2-1			0.042	0.043	0.000	-0.001	-0.001				
W3-D2-2			0.041	0.043	-0.001	-0.001	-0.002	d_{bar}	-0.002		
W3-D3-1			0.043	0.045	0.001	0.002	-0.002	std error	0.001		
W4-D1-1	*PP1* x_{avg}	5.38	0.046	0.046	0.002	0.001	0.000	t	1.796		
W4-D1-2	*PP2* x_{avg}	5.41						s*t	0.001	d_{bar}	-0.002
W4-D2-1								β_1	-0.003	β_1	-0.006
W4-D2-2								β_2	-0.001	β_2	0.006
W4-D3-1			0.043	0.044	-0.002	-0.001	-0.002	**P/F**	**False**	**P/F**	**True**

Sample											
W1-D1-1	*PP1xavg*	0.044	5.9	4.4	0.5	-0.3	1.5				
W1-D1-2	*PP2xavg*	0.049	6.4	4.7	1.0	0.0	1.7				
W1-D2-1			5.8	5.4	0.4	0.8	0.4				
W1-D2-2											
W1-D3-1			3.7	4.1	-1.8	-0.6	-0.4				
W2-D1-1	*PP1xavg*	0.045	5.3	4.9	0.3	0.9	0.4				
W2-D1-2	*PP2xavg*	0.047	5.3	4.5	0.3	0.5	0.8				
W2-D2-1											
W2-D2-2			5.0	2.4	0.0	-1.6	2.6				
W2-D3-1			4.4	4.1	-0.6	0.1	0.3				
W3-D1-1	*PP1xavg*	0.042	6.2	6.1	-0.7	-0.5	0.1				
W3-D1-2	*PP2xavg*	0.043	7.9	6.2	1.0	-0.4	1.7				
W3-D2-1			6.7	7.7	-0.2	1.1	-1.0				
W3-D2-2			8.0	5.2	1.1	-1.4	2.8	d_{bar}	0.71		
W3-D3-1			5.9	7.6	-1.0	1.0	-1.7	std error	0.235		
W4-D1-1	*PP1xavg*	0.044						t	1.782		
W4-D1-2	*PP2xavg*	0.045						s*t	0.419	d_{bar}	0.71
W4-D2-1								β_1	0.289	β_1	-2.287
W4-D2-2								β_2	1.127	β_2	2.287
W4-D3-1								**P/F**	**False**	**P/F**	**True**

Sample											
W1-D1-1	*PP1xavg*	5.5	2.397	2.024	0.194	-0.021	0.373				
W1-D1-2	*PP2xavg*	4.7	2.307	1.944	0.104	-0.101	0.363				
W1-D2-1			1.999	2.186	-0.204	0.141	-0.187				
W1-D2-2											
W1-D3-1			2.108	2.03	-0.095	-0.019	0.082				
W2-D1-1	*PP1xavg*	5.0	2.35	2.308	0.101	0.068	0.042				
W2-D1-2	*PP2xavg*	4.0	2.151	2.268	-0.098	0.028	-0.117				
W2-D2-1											
W2-D2-2			2.233	2.134	-0.016	-0.106	0.099				
W2-D3-1			2.262	2.25	0.013	0.010	0.012				
W3-D1-1	*PP1xavg*	6.9	2.446	2.052	0.400	-0.155	0.394				
W3-D1-2	*PP2xavg*	6.6	2.131	2.303	0.085	0.096	-0.172				
W3-D2-1			1.853	2.095	-0.193	-0.112	-0.242				
W3-D2-2			1.945	2.053	-0.101	-0.154	-0.108	d_{bar}	-0.06		
W3-D3-1			1.853	2.53	-0.193	0.324	-0.678	std error	0.097		
W4-D1-1	*PP1xavg*	#DIV/0!						t	1.796		
W4-D1-2	*PP2xavg*	#DIV/0!	1.513	2.197	0.000	0.000	-0.684	s*t	0.174	d_{bar}	-0.059
W4-D2-1								β_1	-0.233	β_1	-0.351
W4-D2-2								β_2	0.116	β_2	0.351
W4-D3-1								**P/F**	**True**	**P/F**	**True**

Sample													
W1-D1-1	*PP1xavg*	2.203	2.15	2.24	0.189	0.144					-0.089	*PP1xavg*	1.961
W1-D1-2	*PP2xavg*	2.045	2.18	2.29	0.219	0.197					-0.112	*PP2xavg*	2.094
W1-D2-1			1.62	1.79	-0.345	-0.302					-0.176		
W1-D2-2													
W1-D3-1			1.90	2.06	-0.062	-0.038					-0.158		
W2-D1-1	*PP1xavg*	2.249	1.92	1.88	-0.074	-0.295					0.033	*PP1xavg*	1.989
W2-D1-2	*PP2xavg*	2.240	1.89	2.32	-0.104	0.146					-0.438	*PP2xavg*	2.177
W2-D2-1													
W2-D2-2			2.11	2.27	0.120	0.091					-0.159		
W2-D3-1			2.05	2.23	0.058	0.057					-0.187		
W3-D1-1	*PP1xavg*	2.046	2.22	2.25	0.122	0.078					-0.033	*PP1xavg*	2.093
W3-D1-2	*PP2xavg*	2.207	2.00	2.19	-0.093	0.023					-0.193	*PP2xavg*	2.170
W3-D2-1			1.92	2.41	-0.171	0.242					-0.490		
W3-D2-2			2.13	2.10	0.038	-0.073	d_{bar}	0.00			0.034		
W3-D3-1			2.20	1.90	0.102	-0.269	std error	0.052			0.294		
W4-D1-1	*PP1xavg*	1.513	1.97	2.04	-0.055		t	1.782			-0.072	*PP1xavg*	2.027
W4-D1-2	*PP2xavg*	2.197	2.08		0.055		s*t	0.092	d_{bar}	0.022	2.082	*PP2xavg*	2.043
W4-D2-1							β_1	-0.092	β_1	-0.325			
W4-D2-2							β_2	0.092	β_2	0.325			
W4-D3-1							**P/F**	**True**	**P/F**	**True**			

Table A2. FSP Proving Raw Data, Error Analysis and Paired T-tests

pH

Sample	Sample Time	FSP	PP2	$ε_{PP1}$	$ε_{PP2}$			FSP_{avg}-$PP2_{ang}$	Hypotehsized Differnce Test		Revised Limits Test	
RW-W1	T1-1	4.78	4.75	0.09	0.04	FSP_{avg}	4.87	0.02	d_{bar}	0.03	d_{bar}	0.03
	T1-2	4.96	4.83	-0.09	-0.04	$PP2_{avg}$	4.79	0.12	$β_1$	-0.100	$β_1$	-0.190
RW-W2	T2-1	4.89	4.78	-0.02	0.08	FSP_{avg}	4.87	0.11	$β_2$	0.100	$β_2$	0.190
	T2-2	4.85	4.93	0.02	-0.08	$PP2_{avg}$	4.86	-0.09	**P/F**	**True**	**P/F**	**True**
RW-W4	T3-1	5.03	4.97	-0.03	0.07	FSP_{avg}	5.00	0.06				
	T3-2	4.97	5.10	0.03	-0.07	$PP2_{avg}$	5.03	-0.13				
RW-W6	T4-1	5.16	4.93	-0.06	0.07	FSP_{avg}	5.10	0.23				
	T4-2	5.03	5.07	0.07	-0.07	$PP2_{avg}$	5.00	-0.04				
RW-W7	T5-1	5.10	4.92	-0.10	0.09	FSP_{avg}	5.00	0.18				
	T5-2	4.90	5.11	0.10	-0.09	$PP2_{avg}$	5.01	-0.21				
PM1-W1	T1-1	9.83		0.11		FSP_{avg}	9.94		d_{bar}	0.05	d_{bar}	0.05
	T1-2	10.04	9.77	-0.11		$PP2_{avg}$	9.77	0.27	$β_1$	-0.100	$β_1$	-0.190
PM1-W2	T2-1	9.94	9.86	-0.03	-0.02	FSP_{avg}	9.91	0.08	$β_2$	0.100	$β_2$	0.190
	T2-2	9.87	9.83	0.03	0.01	$PP2_{avg}$	9.85	0.04	**P/F**	**True**	**P/F**	**True**
PM1-W4	T3-1	10.14	9.76	-0.02	0.04	FSP_{avg}	10.12	0.39				
	T3-2	10.10	9.83	0.02	-0.04	$PP2_{avg}$	9.79	0.27				
PM1-W6	T4-1	9.85	9.99	-0.03	0.03	FSP_{avg}	9.82	-0.15				
	T4-2	9.79	10.06	0.03	-0.03	$PP2_{avg}$	10.03	-0.27				
PM1-W7	T5-1	9.86	9.76	-0.12	0.05	FSP_{avg}	9.74	0.10				
	T5-2	9.61	9.86	0.12	-0.05	$PP2_{avg}$	9.81	-0.24				
PM3-W1	T1-1	5.41	5.21	0.14	0.09	FSP_{avg}	5.55	0.20	d_{bar}	0.16	d_{bar}	0.16
	T1-2	5.70	5.39	-0.14	-0.09	$PP2_{avg}$	5.30	0.31	$β_1$	-0.100	$β_1$	-0.190
PM3-W2	T2-1	5.48	5.13	0.10	0.09	FSP_{avg}	5.58	0.35	$β_2$	0.100	$β_2$	0.190
	T2-2	5.68	5.30	-0.10	-0.09	$PP2_{avg}$	5.22	0.38	**P/F**	**False**	**P/F**	**True**
PM3-W4	T3-1	5.82	5.56	-0.16	0.05	FSP_{avg}	5.66	0.26				
	T3-2	5.50	5.66	0.16	-0.05	$PP2_{avg}$	5.61	-0.16				
PM3-W6	T4-1	5.55	5.51	-0.19	0.08	FSP_{avg}	5.36	0.04				
	T4-2	5.17	5.67	0.19	-0.08	$PP2_{avg}$	5.59	-0.50				
PM3-W7	T5-1	5.75	5.24	-0.02	0.11	FSP_{avg}	5.73	0.51				
	T5-2	5.71	5.46	0.02	-0.11	$PP2_{avg}$	5.35	0.24				
Floc3-W1	T1-1	5.34	5.28	0.17	0.04	FSP_{avg}	5.51	0.06	d_{bar}	0.07	d_{bar}	0.07
	T1-2	5.67	5.36	-0.17	-0.04	$PP2_{avg}$	5.32	0.32	$β_1$	-0.100	$β_1$	-0.190
Floc3-W2	T2-1	5.53	-	-0.07		FSP_{avg}	5.46		$β_2$	0.100	$β_2$	0.190
	T2-2	5.40	5.44	0.07		$PP2_{avg}$	5.44	-0.04	**P/F**	**True**	**P/F**	**True**
Floc3-W4	T3-1	5.76	5.41	-0.04	0.11	FSP_{avg}	5.72	0.35				
	T3-2	5.68	5.64	0.04	-0.12	$PP2_{avg}$	5.52	0.04				
Floc3-W6	T4-1	5.50	5.58	-0.13	0.01	FSP_{avg}	5.37	-0.08				
	T4-2	5.24	5.61	0.13	-0.02	$PP2_{avg}$	5.60	-0.37				
Floc3-W7	T5-1	5.54	5.30	-0.01	0.06	FSP_{avg}	5.53	0.24				
	T5-2	5.51	5.42	0.02	-0.06	$PP2_{avg}$	5.36	0.09				
Fil3-W1	T1-1	5.38	5.30	0.20	0.02	FSP_{avg}	5.58	0.08	d_{bar}	0.10	d_{bar}	0.10
	T1-2	5.78	5.35	-0.20	-0.02	$PP2_{avg}$	5.32	0.43	$β_1$	-0.100	$β_1$	-0.190
Fil3-W4	T2-1	5.85	5.44	-0.22	0.12	FSP_{avg}	5.63	0.41	$β_2$	0.100	$β_2$	0.190
	T2-2	5.41	5.67	0.22	-0.12	$PP2_{avg}$	5.55	-0.26	**P/F**	**Pass**	**P/F**	**True**
Fil3-W6	T3-1	5.37	5.53	0.09	0.07	FSP_{avg}	5.46	-0.16				
	T3-2	5.55	5.67	-0.09	-0.07	$PP2_{avg}$	5.60	-0.12				
Fil3-W7	T4-1	5.56	5.20	-0.03	0.11	FSP_{avg}	5.53	0.36				
	T4-2	5.50	5.42	0.03	-0.11	$PP2_{avg}$	5.31	0.08				

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Sample	Sample Time	FSP	PP2	$ε_{PP1}$	$ε_{PP2}$			%Variance FSP-PP2	Hypothesized Difference Test		FSP_{avg}-$PP2_{ang}$	Revised Limits Test	
RW-W1	T1-1	0.092	0.097	0.00	0.00	FSP_{avg}	0.10	-5.07	% Variance	-0.80	0.00	d_{bar}	-0.001
	T1-2	0.098	0.100	0.00	0.00	$PP2_{avg}$	0.10	-2.04	$β_1$	-5.000	0.00	$β_1$	-0.006
RW-W2	T2-1	0.093	0.094	0.00	0.00	FSP_{avg}	0.09	-0.71	$β_2$	5.000	0.00	$β_2$	0.006
	T2-2	0.094	0.093	0.00	0.00	$PP2_{avg}$	0.09	1.06	**P/F**	**True**	0.00	**P/F**	**True**
RW-W4	T3-1	0.086		0.00		FSP_{avg}	0.09						
	T3-2	0.090	0.088	0.00		$PP2_{avg}$	0.09	1.49			0.00		
RW-W6	T4-1	0.071	0.070	0.00	0.00	FSP_{avg}	0.07	1.88			0.00		
	T4-2	0.070	0.072	0.00	0.00	$PP2_{avg}$	0.07	-1.90			0.00		
RW-W7	T5-1	0.076	0.075	0.00	0.00	FSP_{avg}	0.07	1.75			0.00		
	T5-2	0.072	0.075	0.00	0.00	$PP2_{avg}$	0.08	-3.69			0.00		
PM1-W1	T1-1	0.112	0.114	0.00	0.00	FSP_{avg}	0.11	-2.09	% Variance	-2.51	0.00	d_{bar}	-0.002
	T1-2	0.113	0.110	0.00	0.00	$PP2_{avg}$	0.11	2.37	$β_1$	-5.000	0.00	$β_1$	-0.006
PM1-W2	T2-1	0.107	0.111	0.00	0.00	FSP_{avg}	0.11	-4.05	$β_2$	5.000	0.00	$β_2$	0.006
	T2-2	0.107	0.110	0.00	0.00	$PP2_{avg}$	0.11	-2.80	**P/F**	**True**	0.00	**P/F**	**True**
PM1-W4	T3-1	0.103	0.109	0.00	0.00	FSP_{avg}	0.10	-5.81			-0.01		
	T3-2	0.103	0.101	0.00	0.00	$PP2_{avg}$	0.11	2.27			0.00		
PM1-W6	T4-1	0.096	0.094	-0.01	0.00	FSP_{avg}	0.09	2.77			0.00		
	T4-2	0.082	0.095	0.01	0.00	$PP2_{avg}$	0.09	-15.85			-0.01		
PM1-W7	T5-1	0.089	0.088	0.00	0.00	FSP_{avg}	0.09	0.38			0.00		
	T5-2	0.087	0.089	0.00	0.00	$PP2_{avg}$	0.09	-2.30			0.00		
PM3-W1	T1-1	0.027	0.030	0.00	0.00	FSP_{avg}	0.03	-11.11	% Variance	-9.09	0.00	d_{bar}	-0.002
	T1-2	0.035	0.029	0.00	0.00	$PP2_{avg}$	0.03	17.14	$β_1$	-5.000	0.01	$β_1$	-0.006
PM3-W2	T2-1	0.030	-	0.00		FSP_{avg}	0.03		$β_2$	5.000		$β_2$	0.006
	T2-2	0.031	0.030	0.00		$PP2_{avg}$	0.03	2.15	**P/F**	**False**	0.00	**P/F**	**True**
PM3-W4	T3-1	0.027	0.030	0.00	0.00	FSP_{avg}	0.03	-9.88			0.00		
	T3-2	0.029	0.032	0.00	0.00	$PP2_{avg}$	0.03	-11.49			0.00		
PM3-W6	T4-1	0.025	0.035	0.00	0.00	FSP_{avg}	0.03	-40.00			-0.01		
	T4-2	0.025	0.025	0.00	0.00	$PP2_{avg}$	0.03	-1.33			0.00		
PM3-W7	T5-1	0.034	0.035	0.00	0.00	FSP_{avg}	0.03	-1.96			0.00		
	T5-2	0.026	0.033	0.00	0.00	$PP2_{avg}$	0.03	-25.32			-0.01		
Floc3-W1	T1-1	0.021	0.035	0.01	0.00	FSP_{avg}	0.03	-66.67	% Variance	-23.99	-0.01	d_{bar}	-0.006
	T1-2	0.031	0.040	-0.01	0.00	$PP2_{avg}$	0.04	-29.03	$β_1$	-5.000	-0.01	$β_1$	-0.006
Floc3-W2	T2-1	0.028	-	0.00		FSP_{avg}	0.03		$β_2$	5.000		$β_2$	0.006
	T2-2	0.028	0.033	0.00		$PP2_{avg}$	0.03	-17.86	**P/F**	**False**	-0.01	**P/F**	**TRUE**
Floc3-W4	T3-1	0.028		0.00		FSP_{avg}	0.03						
	T3-2	0.026	0.032	0.00		$PP2_{avg}$	0.03	-24.36			-0.01		
Floc3-W6	T4-1	0.038	0.031	-0.01	0.00	FSP_{avg}	0.03	18.42			0.01		
	T4-2	0.026	0.037	0.01	0.00	$PP2_{avg}$	0.03	-42.86			-0.01		
Floc3-W7	T5-1	0.025	0.032	0.00	0.00	FSP_{avg}	0.03	-28.38			-0.01		
	T5-2	0.029	0.029	0.00	0.00	$PP2_{avg}$	0.03	-1.16			0.00		
Fil3-W1	T1-1	0.026	0.041	0.01	0.00	FSP_{avg}	0.03	-57.69	% Variance	-14.40	-0.02	d_{bar}	-0.004
	T1-2	0.038	0.038	-0.01	0.00	$PP2_{avg}$	0.04	0.00	$β_1$	-5.000	0.00	$β_1$	-0.006
Fil3-W4	T2-1	0.031	0.039	0.00	0.00	FSP_{avg}	0.03	-24.73	$β_2$	5.000	-0.01	$β_2$	0.006
	T2-2	0.029	0.033	0.00	0.00	$PP2_{avg}$	0.04	-14.94	**P/F**	**False**	0.00	**P/F**	**True**
Fil3-W6	T3-1	0.038	0.029	-0.01	0.00	FSP_{avg}	0.03	23.01			0.01		
	T3-2	0.027	0.037	0.01	0.00	$PP2_{avg}$	0.03	-37.04			-0.01		
Fil3-W7	T4-1	0.034	0.034	0.00	0.00	FSP_{avg}	0.03	1.94			0.00		
	T4-2	0.035	0.037	0.00	0.00	$PP2_{avg}$	0.04	-5.71			0.00		

TOC

Sample	Sample Time	FSP	PP2	εPP1	εPP2			%Variance FSP-PP2	Hypothesized Difference Test		FSP_{avg}-$PP2_{ang}$	Revised Limits Test	
RW-W1	T1-1	2.57	2.15	0.26	0.35	FSP_{avg}	2.83	16.28	% Variance	3.83	0.42	d_{bar}	0.115
	T1-2	3.08	2.86	-0.26	-0.35	$PP2_{avg}$	2.50	7.43	$β_1$	-5.000	0.23	$β_1$	-0.369
RW-W2	T2-1	2.63	2.70	0.02	0.15	FSP_{avg}	2.65	-2.82	$β_2$	5.000	-0.07	$β_2$	0.369
	T2-2	2.68	3.01	-0.02	-0.15	$PP2_{avg}$	2.85	-12.33	**P/F**	**True**	-0.33	**P/F**	**True**
RW-W4	T3-1	2.28	2.56	0.06	-0.17	FSP_{avg}	2.34	-12.47			-0.28		
	T3-2	2.41	2.22	-0.06	0.17	$PP2_{avg}$	2.39	7.69			0.19		
RW-W6	T4-1	2.95	2.40	-0.24	-0.02	FSP_{avg}	2.71	18.56			0.55		
	T4-2	2.47	2.36	0.24	0.02	$PP2_{avg}$	2.38	4.22			0.10		
RW-W7	T5-1	2.75	2.75	0.11	-0.07	FSP_{avg}	2.86	-0.04			0.00		
	T5-2	2.97	2.62	-0.11	0.07	$PP2_{avg}$	2.68	11.79			0.35		
PM1-W1	T1-1	2.83	3.06	0.09	-0.01	FSP_{avg}	2.93	-7.87	% Variance	5.90	-0.22	d_{bar}	0.161
	T1-2	3.02	3.05	-0.09	0.01	$PP2_{avg}$	3.05	-0.83	$β_1$	-5.000	-0.02	$β_1$	-0.369
PM1-W2	T2-1	2.96	2.54	-0.15	-0.04	FSP_{avg}	2.80	14.14	$β_2$	5.000	0.42	$β_2$	0.369
	T2-2	2.65	2.46	0.15	0.04	$PP2_{avg}$	2.50	7.18	**P/F**	**False**	0.19	**P/F**	**True**
PM1-W4	T3-1	2.30	2.11	0.08	0.01	FSP_{avg}	2.37	8.02			0.18		
	T3-2	2.45	2.14	-0.08	-0.01	$PP2_{avg}$	2.12	12.67			0.31		
PM1-W6	T4-1	2.79	2.45	-0.21	0.01	FSP_{avg}	2.58	12.39			0.35		
	T4-2	2.37	2.47	0.21	-0.01	$PP2_{avg}$	2.46	-4.35			-0.10		
PM1-W7	T5-1	2.95	2.57	-0.04	0.09	FSP_{avg}	2.92	13.08			0.39		
	T5-2	2.88	2.75	0.04	-0.09	$PP2_{avg}$	2.66	4.55			0.13		
PM3-W1	T1-1	2.92	3.18		-0.25	FSP_{avg}	2.92	-9.12	% Variance	-0.81	-0.27	d_{bar}	-0.032
	T1-2	-	2.68		0.25	$PP2_{avg}$	2.93		$β_1$	-5.000		$β_1$	-0.369
PM3-W2	T2-1	2.78	-	-0.09		FSP_{avg}	2.69		$β_2$	5.000		$β_2$	0.369
	T2-2	2.60	2.85	0.09		$PP2_{avg}$	2.85	-9.59	**P/F**	**True**	-0.25	**P/F**	**True**
PM3-W4	T3-1	2.40	2.17	0.05	0.01	FSP_{avg}	2.45	9.51			0.23		
	T3-2	2.51	2.18	-0.05	-0.01	$PP2_{avg}$	2.18	12.93			0.32		
PM3-W6	T4-1		2.71			FSP_{avg}	1.19						
	T4-2	1.19				$PP2_{avg}$	2.71						
PM3-W7	T5-1	2.88	2.97	-0.19	-0.17	FSP_{avg}	2.69	-3.20			-0.09		
	T5-2	2.50	2.63	0.19	0.17	$PP2_{avg}$	2.80	-5.41			-0.14		
Floc3-W1	T1-1	3.09	3.19	0.07	-0.45	FSP_{avg}	3.17	-3.23	% Variance	4.79	-0.10	d_{bar}	0.269
	T1-2	3.24	2.30	-0.07	0.45	$PP2_{avg}$	2.75	29.00	$β_1$	-5.000	0.94	$β_1$	-0.369
Floc3-W2	T2-1	2.95	-	0.62		FSP_{avg}	3.57		$β_2$	5.000		$β_2$	0.369
	T2-2	4.18	2.77	-0.62		$PP2_{avg}$	2.77	33.80	**P/F**	**True**	1.41	**P/F**	**True**
Floc3-W4	T3-1	2.74	2.74	-0.30	0.06	FSP_{avg}	2.44	0.15			0.00		
	T3-2	2.14	2.86	0.30	-0.06	$PP2_{avg}$	2.80	-33.33			-0.71		
Floc3-W6	T4-1		2.67			FSP_{avg}	2.65						
	T4-2	2.65				$PP2_{avg}$	2.67						
Floc3-W7	T5-1	3.11		-0.04		FSP_{avg}	3.06						
	T5-2	3.02	2.95	0.04	0.00	$PP2_{avg}$	2.95	2.38			0.07		
Fil3-W1	T1-1	1.83	2.09	-0.13	-0.03	FSP_{avg}	1.70	-14.51	% Variance	-8.32	-0.27	d_{bar}	-0.132
	T1-2	1.56	2.03	0.13	0.03	$PP2_{avg}$	2.06	-29.73	$β_1$	-5.000	-0.47	$β_1$	-0.369
Fil3-W4	T2-1	1.76	1.90	0.00	-0.08	FSP_{avg}	1.76	-7.97	$β_2$	5.000	-0.14	$β_2$	0.369
	T2-2	1.76	1.73	0.00	0.08	$PP2_{avg}$	1.81	1.59	**P/F**	**False**	0.03	**P/F**	**True**
Fil3-W6	T3-1		1.81			FSP_{avg}	1.67						
	T3-2	1.67				$PP2_{avg}$	1.81						
Fil3-W7	T4-1	1.75	1.99	0.13	-0.13	FSP_{avg}	1.88	-13.41			-0.24		
	T4-2	2.01	1.73	-0.13	0.13	$PP2_{avg}$	1.86	14.09			0.28		

DOC

Sample	Sample Time	FSP	PP2	εPP1	εPP2			%Variance FSP-PP2	Hypothesized Difference Test		FSP_{avg}-$PP2_{ang}$	Revised Limits Test	
RW-W1	T1-1	2.83	2.67	0.12	0.05	FSP_{avg}	2.95	5.67	% Variance	1.74	0.16	d_{bar}	0.075
	T1-2	3.07	2.78	-0.12	-0.05	$PP2_{avg}$	2.73	9.42	$β_1$	-5.000	0.29	$β_1$	-0.306
RW-W2	T2-1	2.52	2.86	0.03	-0.14	FSP_{avg}	2.55	-13.42	$β_2$	5.000	-0.34	$β_2$	0.306
	T2-2	2.58	2.58	-0.03	0.14	$PP2_{avg}$	2.72	-0.19	**P/F**	**True**	0.00	**P/F**	**True**
RW-W4	T3-1	2.38	2.35	-0.05		FSP_{avg}	2.33	1.38			0.03		
	T3-2	2.28		0.05		$PP2_{avg}$	2.35						
RW-W6	T4-1	3.00	2.02	-0.41	0.26	FSP_{avg}	2.59	32.77			0.98		
	T4-2	2.19	2.55	0.41	-0.26	$PP2_{avg}$	2.28	-16.52			-0.36		
RW-W7	T5-1	2.65	2.78	0.03	-0.06	FSP_{avg}	2.68	-4.86			-0.13		
	T5-2	2.71	2.67	-0.03	0.06	$PP2_{avg}$	2.73	1.40			0.04		
PM1-W1	T1-1	2.93	3.17	0.05	-0.16	FSP_{avg}	2.98	-8.33	% Variance	-0.43	-0.24	d_{bar}	-0.006
	T1-2	3.03	2.86	-0.05	0.16	$PP2_{avg}$	3.02	5.42	$β_1$	-5.000	0.16	$β_1$	-0.306
PM1-W2	T2-1	2.64	2.85	0.17	-0.14	FSP_{avg}	2.81	-8.11	$β_2$	5.000	-0.21	$β_2$	0.306
	T2-2	2.97	2.58	-0.17	0.14	$PP2_{avg}$	2.71	13.33	**P/F**	**True**	0.40	**P/F**	**True**
PM1-W4	T3-1	2.66	2.58	-0.11	-0.18	FSP_{avg}	2.55	3.08			0.08		
	T3-2	2.44	2.22	0.11	0.18	$PP2_{avg}$	2.40	9.09			0.22		
PM1-W6	T4-1	2.42	2.67	-0.13	-0.22	FSP_{avg}	2.29	-10.28			-0.25		
	T4-2	2.16	2.23	0.13	0.22	$PP2_{avg}$	2.45	-2.82			-0.06		
PM1-W7	T5-1	2.73	2.89	-0.03	-0.12	FSP_{avg}	2.69	-5.94			-0.16		
	T5-2	2.66	2.65	0.03	0.12	$PP2_{avg}$	2.77	0.26			0.01		
PM3-W1	T1-1	2.12	1.70		0.18	FSP_{avg}	2.12	19.91	% Variance	-4.33	0.42	d_{bar}	-0.076
	T1-2	-	2.06		-0.18	$PP2_{avg}$	1.88		$β_1$	-5.000		$β_1$	-0.306
PM3-W2	T2-1	1.81	-	-0.03		FSP_{avg}	1.78		$β_2$	5.000		$β_2$	0.306
	T2-2	1.75	1.96	0.03		$PP2_{avg}$	1.96	-12.26	**P/F**	**True**	-0.21	**P/F**	**True**
PM3-W4	T3-1	1.64	1.71	0.15	-0.03	FSP_{avg}	1.79	-3.71			-0.06		
	T3-2	1.94	1.65	-0.15	0.03	$PP2_{avg}$	1.68	15.28			0.30		
PM3-W6	T4-1		1.82			FSP_{avg}	1.62						
	T4-2	1.62				$PP2_{avg}$	1.82						
PM3-W7	T5-1	2.40	2.33	-0.19	0.32	FSP_{avg}	2.20	2.88			0.07		
	T5-2	2.01	2.98	0.19	-0.32	$PP2_{avg}$	2.65	-48.06			-0.97		
Floc3-W1	T1-1	1.93	2.04	0.03	-0.04	FSP_{avg}	1.96	-5.38	% Variance	-0.24	-0.10	d_{bar}	-0.006
	T1-2	1.99	1.96	-0.03	0.04	$PP2_{avg}$	2.00	1.71	$β_1$	-5.000	0.03	$β_1$	-0.306
Floc3-W2	T2-1	1.79	-	0.05		FSP_{avg}	1.85		$β_2$	5.000		$β_2$	0.306
	T2-2	1.90	1.94	-0.05		$PP2_{avg}$	1.94	-2.00	**P/F**	**True**	-0.04	**P/F**	**True**
Floc3-W4	T3-1	1.86	1.83	0.02	-0.05	FSP_{avg}	1.88	1.83			0.03		
	T3-2	1.91	1.72	-0.02	0.05	$PP2_{avg}$	1.77	9.96			0.19		
Floc3-W6	T4-1		1.87			FSP_{avg}	1.76						
	T4-2	1.76				$PP2_{avg}$	1.87						
Floc3-W7	T5-1	2.06		-0.02		FSP_{avg}	2.04						
	T5-2	2.02	2.17	0.02		$PP2_{avg}$	2.17	-7.54			-0.15		
Fil3-W1	T1-1	1.95	2.02	-0.17	-0.03	FSP_{avg}	1.78	-3.90	% Variance	-5.15	-0.08	d_{bar}	-0.075
	T1-2	1.62	1.97	0.17	0.03	$PP2_{avg}$	2.00	-22.04	$β_1$	-5.000	-0.36	$β_1$	-0.306
Fil3-W4	T2-1	1.94	2.20	-0.02	-0.23	FSP_{avg}	1.92	-13.42	$β_2$	5.000	-0.26	$β_2$	0.306
	T2-2	1.89	1.74	0.02	0.23	$PP2_{avg}$	1.97	8.34	**P/F**	**False**	0.16	**P/F**	**True**
Fil3-W6	T3-1		1.84			FSP_{avg}	1.58						
	T3-2	1.58				$PP2_{avg}$	1.84						
Fil3-W7	T4-1	1.72	1.96	0.29	0.02	FSP_{avg}	2.02	-13.64			-0.24		
	T4-2	2.31	1.99	-0.29	-0.02	$PP2_{avg}$	1.98	13.77			0.32		

APPENDIX B – Chapter 5 Raw and Supplemental Data

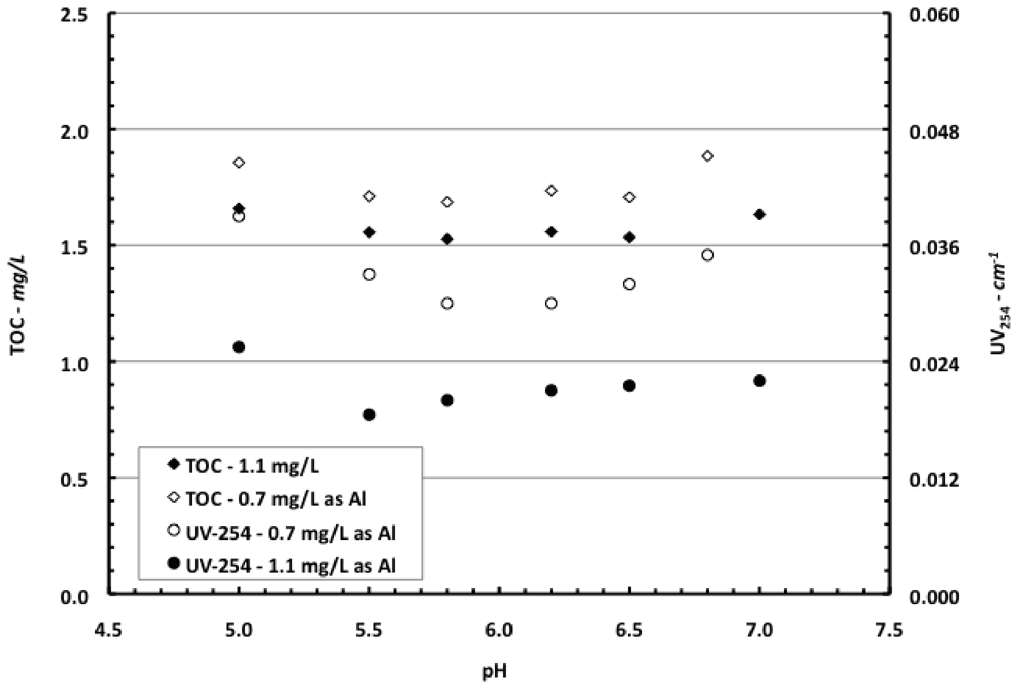


Figure B1. TOC and UV_{254} profiles for Alum dosed at 0.7 and 1.1-mg/L as Al over a range of pH values.

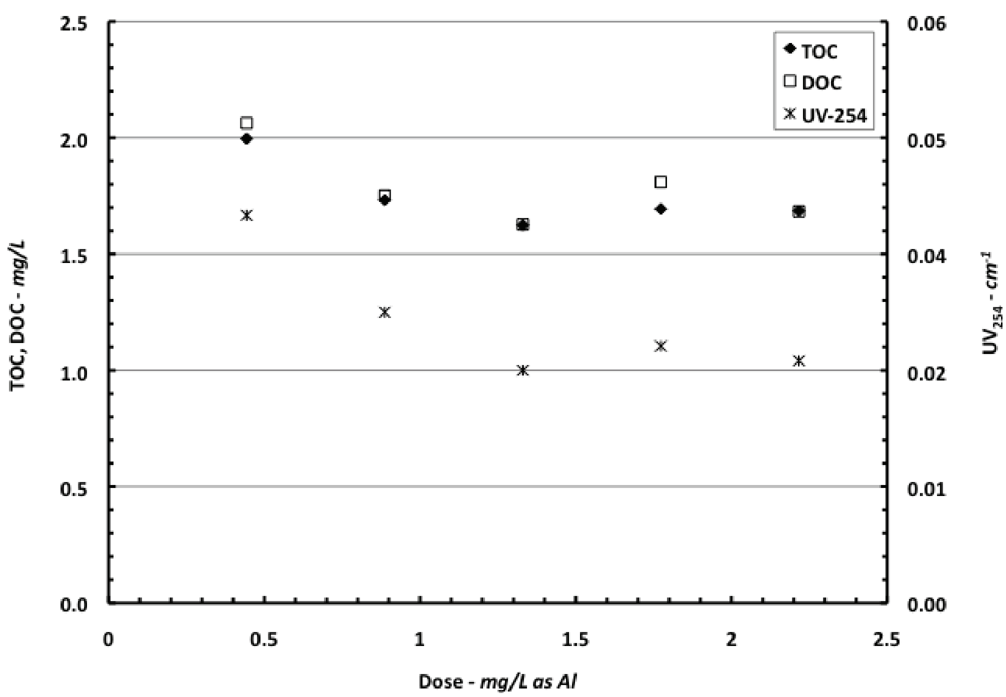


Figure B2. TOC, DOC and UV_{254} results for Alum at pH = 5.5.

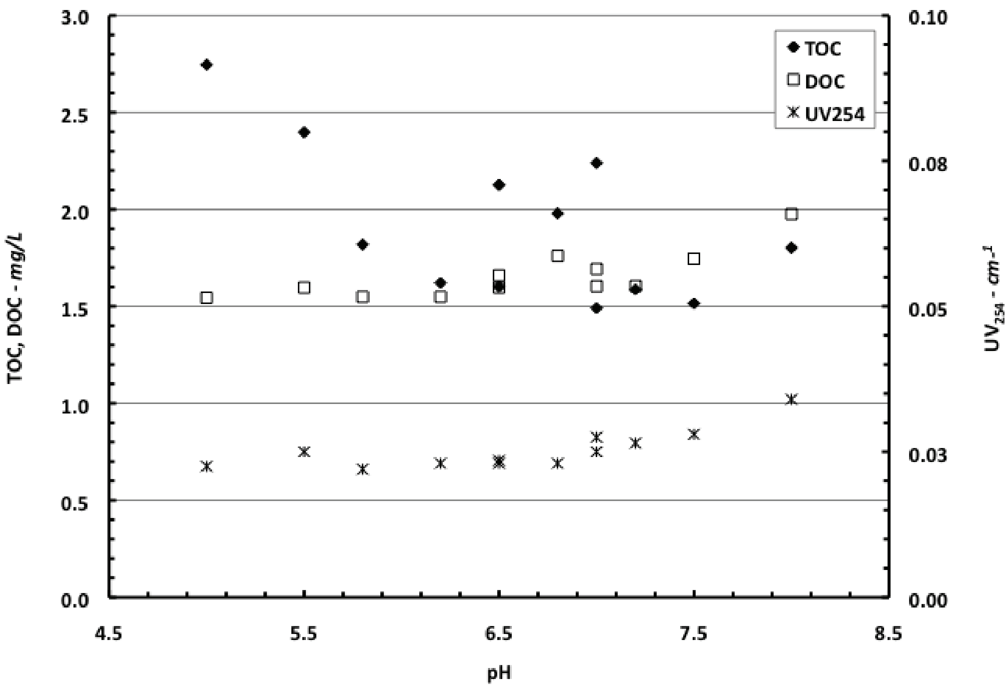


Figure B3. TOC, DOC and UV_{254} profiles for PACl (MBNS) dosed at 1.65-mg/L as Al over a range of pH values.

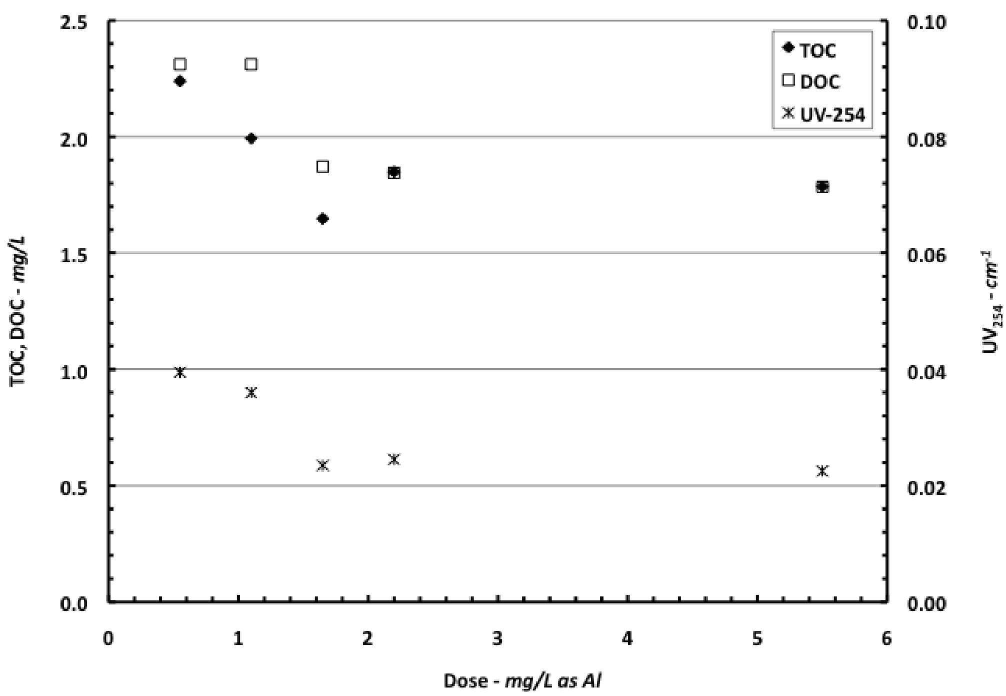


Figure B4. TOC, DOC and UV_{254} results for PACl (MBNS) at pH = 6.0.

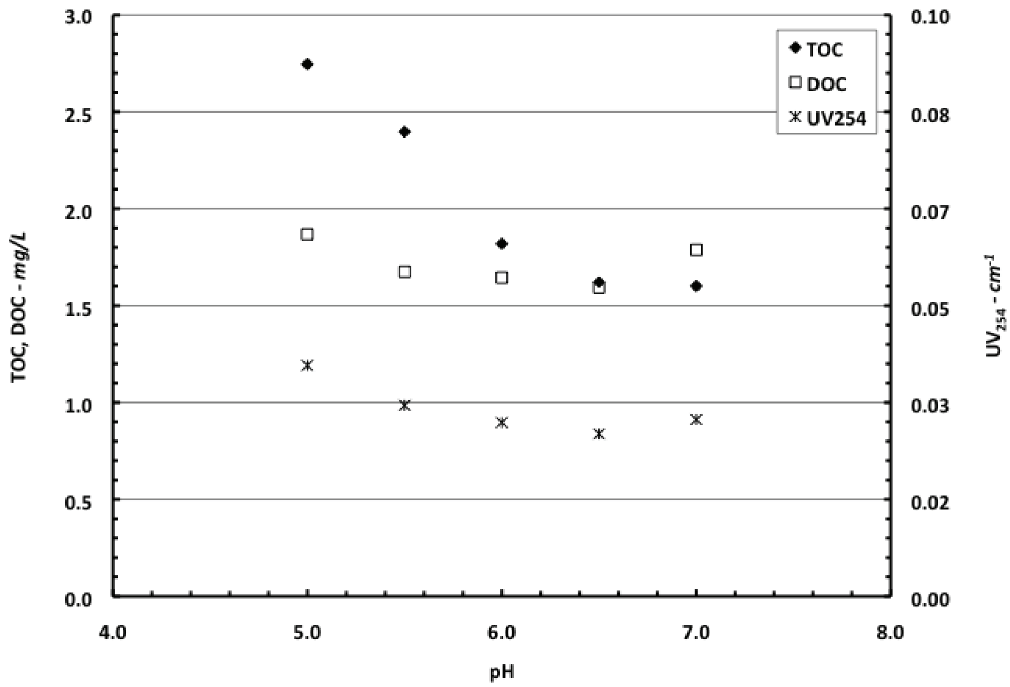


Figure B5. TOC, DOC and UV_{254} profiles for ACH (HBNS) dosed at 4.8-mg/L as Al over a range of pH values.

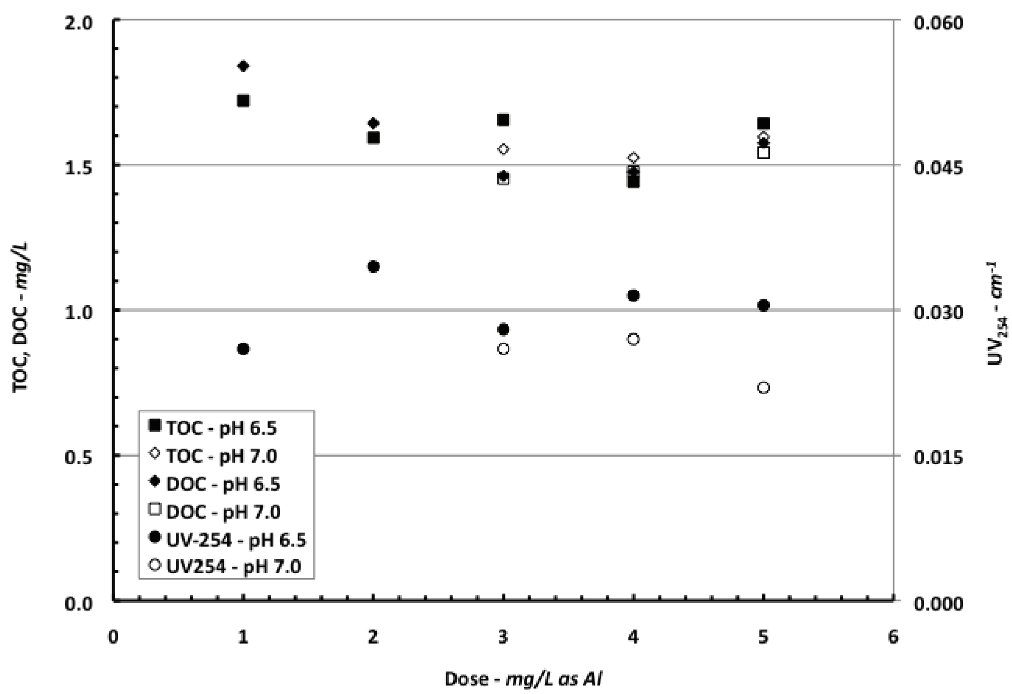


Figure B6. TOC, DOC and UV_{254} results for ACH (HBNS) at pH = 6.5 and 7.0.

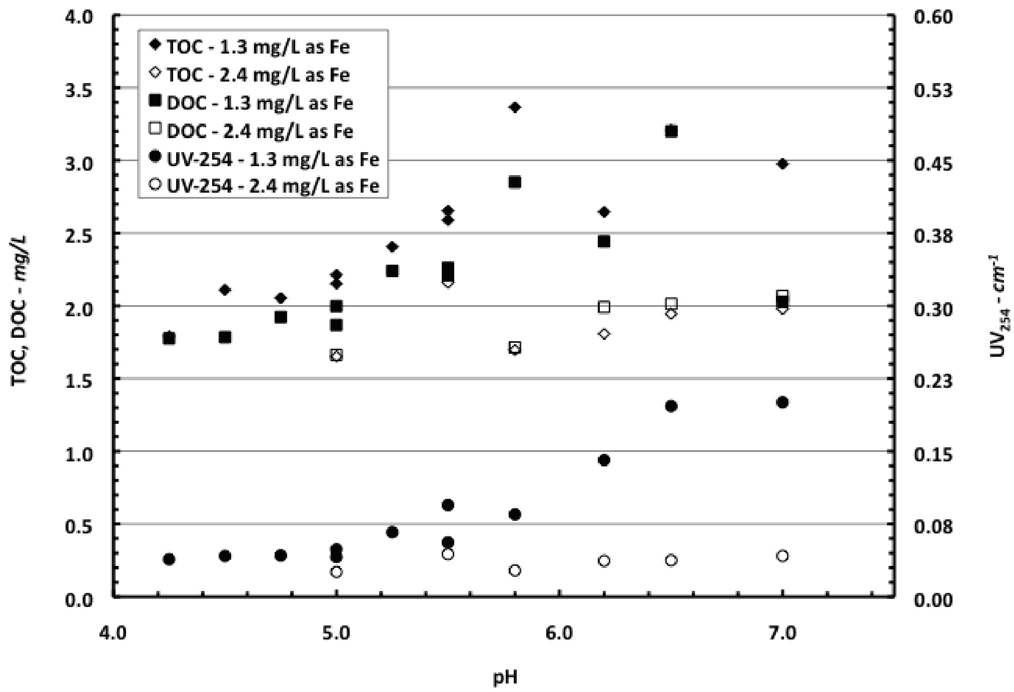


Figure B7. TOC, DOC and UV_{254} profiles for Ferric Sulfate dosed at 1.1-mg/L and 2.0-mg/L as Fe.

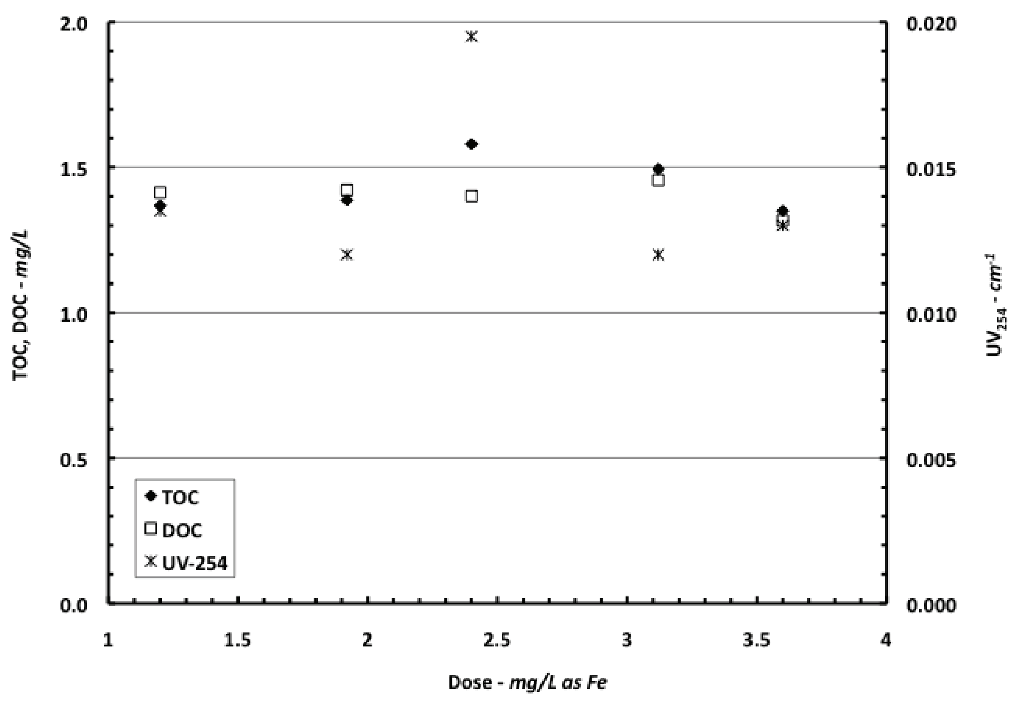


Figure B8. TOC, DOC and UV_{254} profiles for Ferric Sulfate at pH = 4.5.

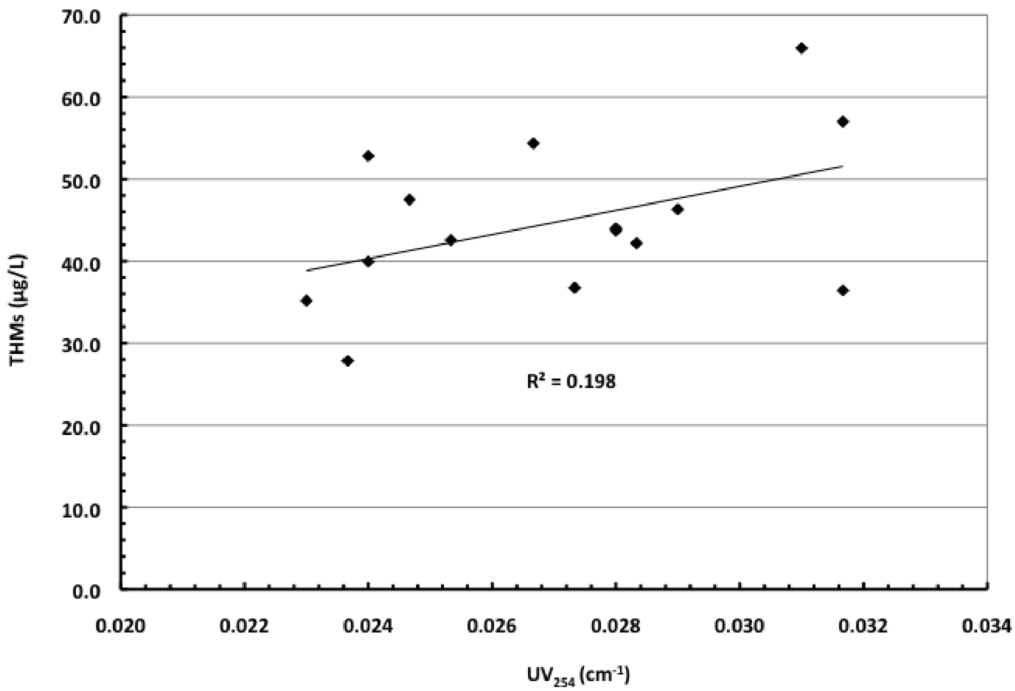


Figure B9. UV_{254}-THM relationship for optimal coagulation trials.

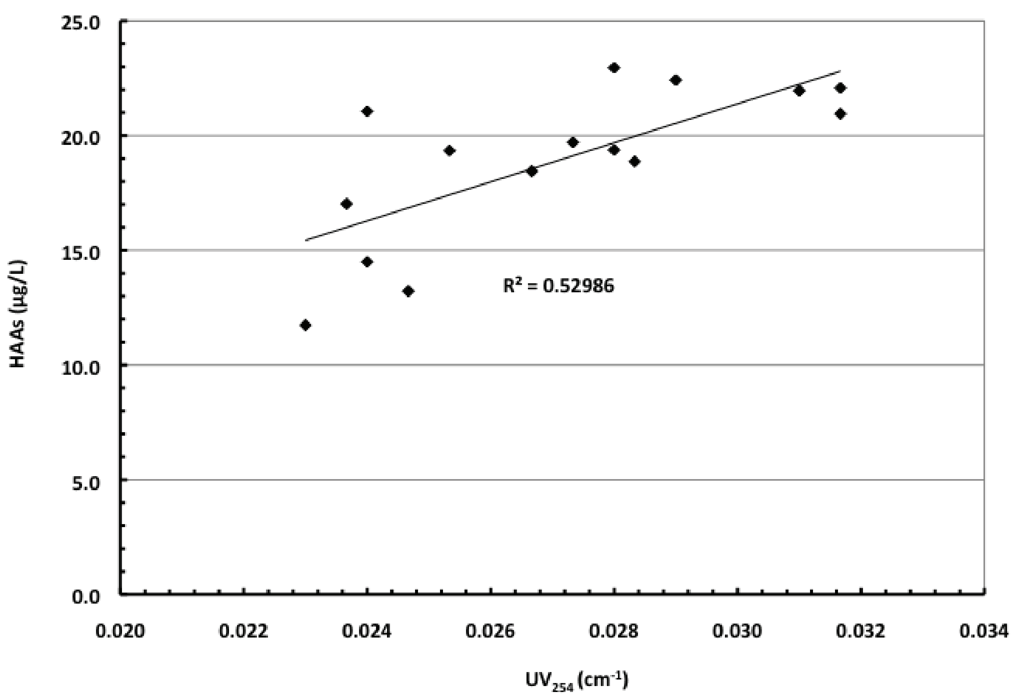


Figure B10. UV_{254}-HAA relationship for optimal coagulation trials.

Table B1. Bench-scale SEC Data

Alum Dose 0.7-mg/L as Al, pH = 5.5						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	7.591	24398.2	56.136	73539.5	162578.7	13355.9
2,3	16.35	2346.6	5.402	827.8	1201.1	668.5
4	17.023	7426.2	17.086	477.4	668.5	332.7
5	17.953	3347.5	7.702	279.4	332.7	228.8
6	18.629	2136.3	4.915	198	228.8	163.1
7	19.263	662.9	1.525	143.5	163.1	120.8
8	20.06	3143.9	7.234	66.2	120.8	26.3

Alum Dose 0.7-mg/L as Al, pH = 5.5						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	7.698	31649.8	71.461	122580.3	244212.4	49468.5
2,3	16.469	1539.1	3.475	1448.8	1849.6	1219.2
4	17.2	4035.2	9.111	918.5	1219.2	690.3
5	17.993	2483.9	5.608	569.8	690.3	461.4
6	18.432	1917.8	4.33	388.2	461.4	308.4
7	19.256	517.8	1.167	274.1	308.4	236.3
8	19.95	2146.8	4.847	148.8	224.1	82.9

Total

Alum Dose 0.7-mg/L as Al, pH = 5.5						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	8.43	1111.1	1.973	80270.1	105699.1	61213
2,3	16.352	10833.2	19.24	1694.8	4156.1	1131.7
4	16.989	14258.4	25.323	899.2	1131.7	690.3
5	17.675	8863.8	15.742	571.6	690.3	461.4
6	18.665	6145.9	10.915	389.9	461.4	308.4
7	19.421	2036.8	3.617	266.7	308.4	227.2
8	19.932	13057.1	23.189	88.7	227.2	6

Alum Dose 1.3-mg/L as Al, pH = 5.8						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	7.699	10534.3	19.739	119082.4	204363.7	61677.3
2,3	16.344	10623.6	19.907	1512.4	2929	1117.9
4	17.012	12910.6	24.192	895.3	1117.9	690.3
5	17.747	7526.6	14.104	573.4	690.3	461.4
6	18.396	4904.4	9.19	389.7	461.4	308.4
7	19.2	1346.9	2.524	267.7	308.4	224.4
8	20.567	5520.1	10.344	131.6	224.4	47.5

Alum Dose 1.3-mg/L as Al, pH = 5.8						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	8.373	2433.1	4.462	91697.4	155642.4	51013.3
2,3	16.354	12776.7	23.429	1526.1	3843.8	1125.4
4	16.976	16390.5	30.055	900.2	1125.4	690.3
5	17.622	9220.3	19.907	573.4	690.3	461.4
6	18.388	5762.5	10.567	391.5	461.4	308.4
7	19.248	1675.6	3.073	265	308.4	224.4
8	20.208	6275.6	11.508	129.8	224.4	44.7

Alum Dose 1.3-mg/L as Al, pH = 5.8						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	8.26	2197.8	3.994	80656.2	123145.1	48847
2,3	16.369	15318.8	27.836	1613.4	4407.8	1130.5
4	17.014	16390.4	30.764	903.9	1130.5	690.3
5	17.81	9012.9	16.377	574	690.3	461.4
6	18.688	5486.7	9.97	392	461.4	308.4
7	19.288	1372.1	2.493	265.8	308.4	224.4
8	20.162	4714.3	8.566	132.9	224.4	45.4

Ferric Sulfate Dose 1.9-mg/L as Al, pH = 4.5						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
2,3	16.427	7724.2	18.3945875	1447.6	2795.4	1128.8
4	16.987	12685.3	30.2090651	880.3	1128.8	690.3
5	17.793	8288.2	19.7377101	563.8	690.3	461.4
6	18.433	5544.4	13.2035617	386.7	461.4	308.4
7	19.223	1561.8	3.71930643	263.4	308.4	224.2
8	20.138	6187.8	14.7357692	101.1	224.2	41.1
		41991.7				

Ferric Sulfate Dose 1.9-mg/L as Al, pH = 4.5						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
2,3	16.391	8209.9	18.515119	1620.5	3551.5	1102.5
4	17.033	11973.5	27.0028596	885.1	1102.5	690.3
5	17.928	8528.6	19.2338571	570.3	690.3	461.4
6	18.43	5847	13.186263	389.8	461.4	308.4
7	19.227	1806	4.07292475	265.5	308.4	224.4
8	20.165	7976.6	17.9889765	112.9	224.4	28.3
		44341.6				

Ferric Sulfate Dose 1.9-mg/L as Al, pH = 4.5						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
2,3	16.419	7303	18.0677435	1555.4	3098.7	1195.7
4	17.007	14560.3	36.0224245	920.1	1195.7	690.3
5	17.94	8151.2	20.1662044	571.7	690.3	461.4
6	18.605	5297.3	13.1056083	391.9	461.4	308.4
7	19.273	1266.9	3.13433168	267.6	308.4	224.4
8	20.178	3841.4	9.50368752	145	224.4	67.3
		40420.1	100			

PACl Dose 1.65-mg/L as Al, pH = 6.0						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
2,3	16.425	6755.9	15.281	1740	3939.9	1181.2
4	17.038	12733.4	28.802	915.7	1181.2	702.8
5	17.988	8800.3	19.906	572.6	702.8	453.8
6	18.722	5288.6	11.962	386.9	453.8	308.9
7	19.21	1792.5	4.054	259.3	308.9	213.6
8	20.023	8839.6	19.994	94.8	213.6	14.5

PACl Dose 1.65-mg/L as Al, pH = 6.0						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
2,3	16.41	7591.4	19.071	1673.6	4215.1	1182.7
4	17.002	13292.6	33.393	918.6	1182.7	697.5
5	17.815	8625.3	21.668	564.1	697.5	439.9
6	18.538	4417.6	11.098	377.9	439.9	291.8
7	19.435	1075.1	2.701	251.1	291.8	213.4
8	20.088	4804.3	12.069	109.9	213.4	18.5

ACH Dose 4.0-mg/L as Al, pH = 7.0						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	5.405	3522.8	7.686	226854.7	466460.2	93968.7
2	8.6	1703.4	3.716	60358.1	93968.7	35446
1		5226.2				
2,3	16.369	5033.4	10.982	1921.3	4649.1	1161.7
4	17.074	10848.9	23.67	901.3	1161.7	700.5
5	17.958	9016	19.671	562.9	700.5	439.9
6	18.697	5119.4	11.17	375	439.9	291.8
7	19.833	1741	3.798	250.7	291.8	213.4
8	20.13	8848.3	19.305	105.7	213.4	17.6

ACH Dose 4.0-mg/L as Al, pH = 7.0						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	7.79	7874.5	18.35	113740.8	270520.7	33557
2,3	16.334	6379.4	14.866	1926.5	4507.1	1185.3
4	17.025	10611.2	24.728	912	1185.3	700.5
5	17.83	7749.4	18.059	564.3	700.5	439.9
6	18.578	4371.6	10.187	374.1	439.9	291.8
7	19.405	1073.6	2.502	258.9	291.8	222.7
8	20.044	4852.8	11.309	138.2	222.7	58.9

ACH Dose 4.0-mg/L as Al, pH = 7.0						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
2,3	16.4	5535.8	16.995	946.7	2161.2	606.1
4	17.036	9533	29.267	482.3	606.1	378.5
5	17.982	8690.6	26.681	297.3	378.5	224.9
6	18.502	3899.1	11.971	194.8	224.9	156.3
7	19.418	1407.8	4.322	128.2	156.3	103.3
8	20.004	3506.3	10.764	68.7	103.3	33.7

Raw Water						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	8.308	1620.5	1.531	52760.8	73077.5	35978.78
2	15.015	27354.3	25.842	1275.1	4314.7	833.1
3	16.285	19521.7	18.442	716.2	833.1	609.5
2,3		46876				
4	16.822	25622.8	24.206	488.6	609.5	366.6
5	17.774	14139.1	13.357	295.9	366.6	225.8
6	19.133	6395.4	6.042	192.7	225.8	150.7
7	19.965	5514.4	5.209	103.4	150.7	63.8
8	21.432	5684.8	5.37	40	63.8	17.7

Raw Water						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	7.685	11980.1	12.053	116454.1	268970.3	40632.5
2,3	16.315	39611.4	39.852		7304.1	1117.5
4	16.935	19848.8	1.969	911.9	1117.5	702.8
5	17.952	11007	11.074	577.6	702.8	453.8
6	18.401	5979.1	6.015	385.6	453.8	308.9
7	19.274	2375.2	2.39	262.5	308.9	213.6
8	20.043	8594.5	8.647	109.2	213.6	22

JM_Raw_Sep24-09001						
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	7.678	26093.2	34.587	123993.9	268970.3	52387.1
2	15.999	11879.1	15.746	2243.6	7304.1	1584.1
3	16.263	11347.2	15.041	1338.4	1584.1	1117.5
2,3		23226.3				
4	16.908	11913.5	15.791	913.2	1117.5	702.8
5	17.757	6752.1	8.95	568.4	702.8	435.8
6	18.605	2927.6	3.881	377.2	435.8	308.9
7	19.161	1305.7	1.731	263	308.9	213.6
8	20.041	3224.1	4.274	147.8	213.6	79.8

Table B2. Pilot-scale SEC Data

27-May-10 ACH		24hr				
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	17.017	4146.9	7.955759767	1166.3	2002.3	971.8
2	17.447	10876.5	20.86638721	827.4	971.8	709.5
3	18.045	17445.1	33.46813878	570.4	709.5	433.4
4	19.014	12222.5	23.44866617	341.3	433.4	258
5	19.888	4009.9	7.69292751	235.6	258	199.8
6	20.54	2034.8	3.903730491	155.4	195.7	138
7	21.169	1388.8	2.664390066	122.1	138	102
		52124.5				

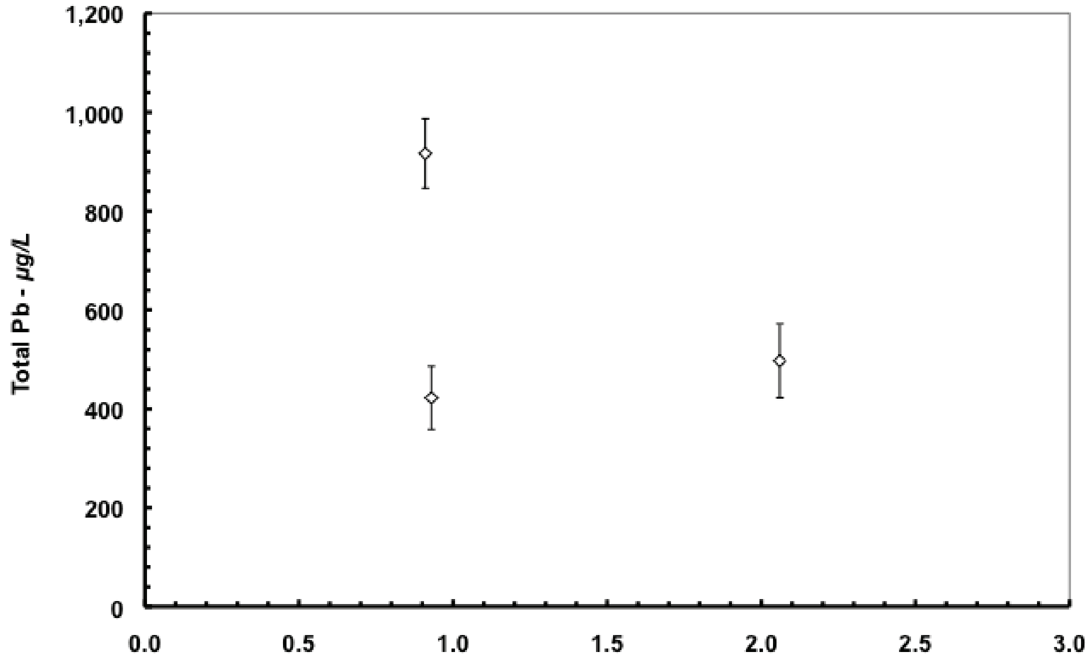
27-May-10 Alum		24h				
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	17.021	3894.3	7.83685938	1175.4	1835	969.2
2	17.412	10372.1	20.8727343	815.2	969.2	681.8
3	18.075	15368.9	30.9282562	559.5	681.8	427.3
4	19.056	11344.3	22.8291821	338.2	427.3	257.5
5	19.876	3923.5	7.895621236	235.1	257.5	203.1
6	20.55	2780.5	5.595456823	166.3	199.1	138.9
7	21.142	2008.5	4.041889958	119.5	138.9	93.7
		49692.1				

27-May-10 FSP		24h				
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	17.023	2399.5	5.157863512	1126.1	1474.5	979.4
2	17.414	8723.1	18.75080608	816.3	979.4	682.9
3	18.071	14656.9	31.5058511	559	682.9	427
4	19.057	11324.9	24.3435251	337.2	427	258.4
5	19.854	4170.5	8.964730059	235.5	258.4	201.6
6	20.579	2675.4	5.750926459	164.6	196.5	138
7	21.213	2570.9	5.526297688	116.4	138	86.5
		46521.2				

27-May-10 Raw		24h				
Peak	RT	Area	%Area	Mw	StartMw	EndMw
1	16.961	27372.6	28.94002045	1236.3	2368.8	932.5
2	17.407	21594.2	22.83073546	807.8	932.5	681
3	18.068	23594.2	24.94526024	554.8	681	411.1
4	19.009	13403.9	14.17143933	334.2	411.1	258
5	19.856	4228.5	4.470634009	233.6	253.8	205
6	20.512	2326.1	2.459298041	165.4	196.5	138.4
7	21.137	2064.4	2.182612474	118.3	138.4	90.5
		94583.9				

APPENDIX C – Chapter 6 Raw and Supplemental Data

a.) Pb pipe – Pb:Sn solder – Cu pipe



b.) Cu pipe – Pb:Sn solder – Cu pipe

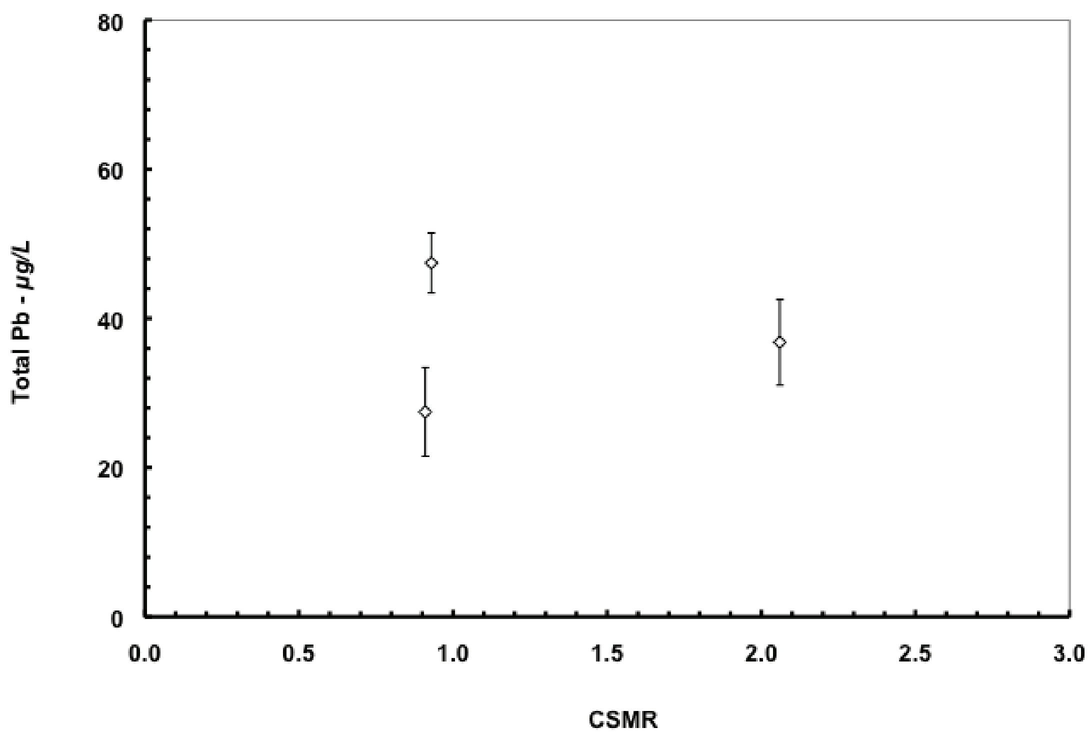


Figure C1. CSMR plotted against average total mass of lead release per wetted lead surface area (μg/cm^2) for both pipe scenarios and each water condition evaluated during Weeks 17 through 27 of this study.

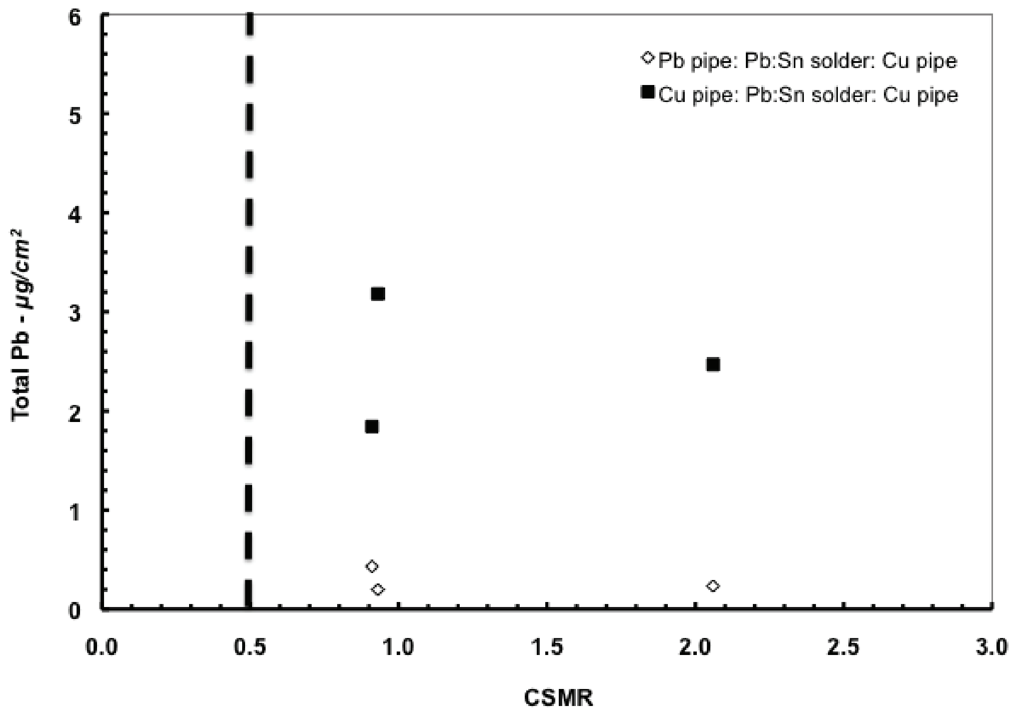
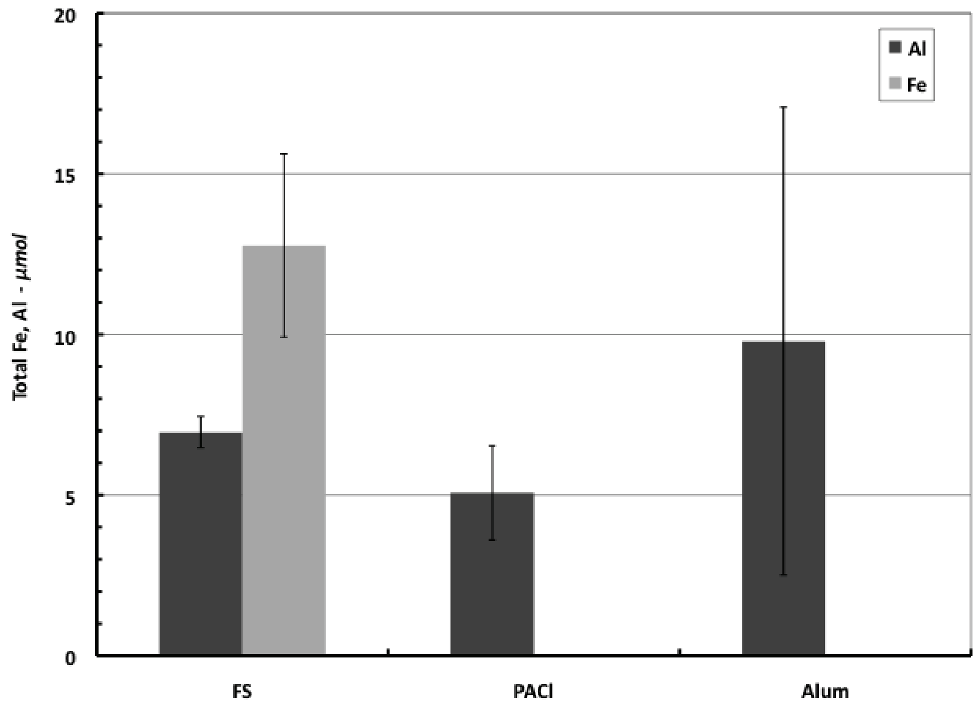


Figure C2. CSMR plotted against average total mass of lead release per wetted lead surface area (μg/cm^2) for both pipe scenarios and each water condition evaluated during Weeks 17 through 27 of this study. The dashed line represents the critical CSMR threshold of 0.5 mg of chloride per mg of sulfate.

a.) Pb pipe – Pb:Sn solder – Cu pipe



b.) Cu pipe – Pb:Sn solder – Cu pipe

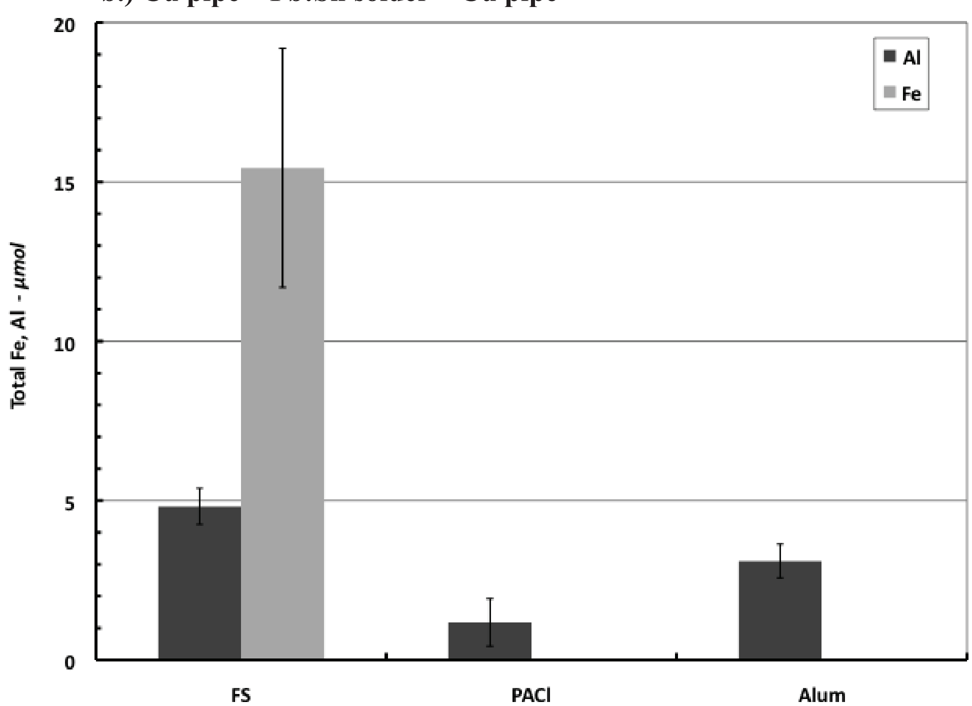


Figure C3. Average bulk water total iron and aluminum release (μmol) for each water condition during Weeks 5 through 9 of this study. Data from the duplicate pipes were averaged to obtain the comparisons in this figure. The error bars indicate the standard deviation of the data.

(FS = ferric sulfate, PACl = polyaluminum chloride, Alum = aluminum sulfate)

Table C1. Total and Dissolved Lead

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Cu-1	2853.000	2863.000	2866.000	2861.000	7.100	0.250	ALUM-Cu-1	W1-W	2861.00	2632.00	1.00	2533.00	2861.00
W1-F	ALUM-Cu-1	2493.000	2444.000	2619.000	2519.000	90.400	3.590	ALUM-Cu-1	W1-F	2519.00	2434.00	2.00	2102.00	2519.00
W2-M	ALUM-Cu-1	2496.000	2658.000	2584.000	2579.000	81.000	3.140	ALUM-Cu-1	W2-M	2579.00	2350.00	3.00	2018.00	2579.00
W2-W	ALUM-Cu-1	2384.000	2352.000	2420.000	2385.000	33.800	1.420	ALUM-Cu-1	W2-W	2385.00	2204.00	4.00	663.25	2385.00
W2-F	ALUM-Cu-1	1445.000	1579.000	1749.000	1591.000	152.000	9.550	ALUM-Cu-1	W2-F	1591.00	1752.00	5.00	282.67	1591.00
W3-M	ALUM-Cu-1	2475.000	2573.000	2541.000	2530.000	49.900	1.970	ALUM-Cu-1	W3-M	2530.00	2429.50	6.00	280.47	2530.00
W3-W	ALUM-Cu-1	2098.000	2059.000	2030.000	2062.000	34.000	1.650	ALUM-Cu-1	W3-W	2062.00	1961.50	7.00	171.78	2062.00
W3-F	ALUM-Cu-1	1612.000	1691.000	1579.000	1627.000	57.900	3.560	ALUM-Cu-1	W3-F	1627.00	1663.00	8.00	103.98	1627.00
W4-M	ALUM-Cu-1	1012.000	954.300	921.400	962.500	45.710	4.750	ALUM-Cu-1	W4-M	962.50	943.00	9.00	107.59	962.50
W4-W	ALUM-Cu-1	714.900	541.900	543.800	600.200	99.330	16.550	ALUM-Cu-1	W4-W	600.20	609.15	10.00	115.84	600.20
W4-F	ALUM-Cu-1	421.100	444.500	428.400	431.300	11.960	2.770	ALUM-Cu-1	W4-F	431.30	437.60	11.00	100.15	431.30
W5-M	ALUM-Cu-1	222.900	231.700	286.200	246.900	34.300	13.890	ALUM-Cu-1	W5-M	246.90	265.30	12.00	87.01	246.90
W5-W	ALUM-Cu-1	310.900	193.900	306.500	270.400	66.340	24.530	ALUM-Cu-1	W5-W	270.40	295.10	13.00	85.77	270.40
W5-F	ALUM-Cu-1	302.200	300.100	286.600	296.300	8.470	2.860	ALUM-Cu-1	W5-F	296.30	287.60	14.00	89.55	296.30
W6-M	ALUM-Cu-1	288.700	254.500	235.400	259.500	27.040	10.420	ALUM-Cu-1	W6-M	259.50	267.50	15.00	181.55	259.50
W6-W	ALUM-Cu-1	152.800	103.900	110.000	122.200	26.640	21.790	ALUM-Cu-1	W6-W	122.20	252.90	16.00	149.34	122.20
W6-F	ALUM-Cu-1	337.000	338.700	318.300	331.400	11.310	3.410	ALUM-Cu-1	W6-F	331.40	321.00	17.00	51.80	331.40
W7-M	ALUM-Cu-1	196.800	191.100	179.900	189.200	8.570	4.530	ALUM-Cu-1	W7-M	189.20	191.90	18.00	41.72	189.20
W7-W	ALUM-Cu-1	253.500	201.000	220.300	224.900	26.550	11.800	ALUM-Cu-1	W7-W	224.90	212.15	19.00	50.53	224.90
W7-F	ALUM-Cu-1	130.700	127.900	144.700	134.500	8.980	6.680	ALUM-Cu-1	W7-F	134.50	111.29	20.00	60.70	134.50
W8-M	ALUM-Cu-1	105.500	97.700	125.600	109.600	14.330	13.070	ALUM-Cu-1	W8-M	109.60	107.45	21.00	50.18	109.60
W8-W	ALUM-Cu-1	103.100	110.300	109.800	107.800	4.010	3.720	ALUM-Cu-1	W8-W	107.80	103.05	22.00	44.10	107.80
W8-F	ALUM-Cu-1	103.600	105.400	113.700	107.600	5.370	4.990	ALUM-Cu-1	W8-F	107.60	101.46	23.00	46.75	107.60
W9-M	ALUM-Cu-1	141.800	142.800	149.900	144.800	4.380	3.020	ALUM-Cu-1	W9-M	144.80	126.15	24.00	51.76	144.80
W9-W	ALUM-Cu-1	100.000	105.600	101.500	102.400	2.860	2.790	ALUM-Cu-1	W9-W	102.40	100.61	25.00	45.79	102.40
W9-F	ALUM-Cu-1	98.530	97.050	95.990	97.190	1.279	1.320	ALUM-Cu-1	W9-F	97.19	96.02	26.00	34.15	97.19
W10-M	ALUM-Cu-1	100.400	95.290	98.590	98.080	2.571	2.620	ALUM-Cu-1	W10-M	98.08	96.34	27.00	40.55	98.08
W10-W	ALUM-Cu-1	92.780	95.460	96.340	94.860	1.854	1.960	ALUM-Cu-1	W10-W	94.86	93.07			94.86
W10-F	ALUM-Cu-1	175.500	169.400	169.400	171.500	3.630	2.120	ALUM-Cu-1	W10-F	171.50	158.10			171.50
W11-M	ALUM-Cu-1	137.700	130.600	136.300	134.900	3.730	2.760	ALUM-Cu-1	W11-M	134.90	116.93			134.90
W11-W	ALUM-Cu-1	89.650	81.530	99.400	90.190	8.944	9.920	ALUM-Cu-1	W11-W	90.19	89.11			90.19
W11-F	ALUM-Cu-1	88.390	98.400	106.200	97.660	8.935	9.150	ALUM-Cu-1	W11-F	97.66	94.40			97.66
W12-M	ALUM-Cu-1	93.190	103.000	97.840	98.020	0.925	5.020	ALUM-Cu-1	W12-M	98.02	92.80			98.02
W12-W	ALUM-Cu-1	89.980	84.590	85.740	86.770	2.840	3.270	ALUM-Cu-1	W12-W	86.77	85.34			86.77
W12-F	ALUM-Cu-1	96.350	85.770	86.920	89.680	5.807	6.480	ALUM-Cu-1	W12-F	89.68	82.90			89.68
W13-M	ALUM-Cu-1	92.950	95.830	97.900	95.560	2.483	2.600	ALUM-Cu-1	W13-M	95.56	93.54			95.56
W13-W	ALUM-Cu-1	70.820	69.250	70.730	70.270	0.882	1.260	ALUM-Cu-1	W13-W	70.27	75.25			70.27
W13-F	ALUM-Cu-1	96.890	97.120	103.500	99.160	3.750	3.780	ALUM-Cu-1	W13-F	99.16	88.52			99.16
W14-M	ALUM-Cu-1	79.740	79.150	77.370	78.750	1.237	1.570	ALUM-Cu-1	W14-M	78.75	85.69			78.75
W14-W	ALUM-Cu-1	102.200	106.700	98.520	102.500	4.100	4.000	ALUM-Cu-1	W14-W	102.50	96.73			102.50
W14-F	ALUM-Cu-1	77.980	78.980	77.290	78.080	0.851	1.090	ALUM-Cu-1	W14-F	78.08	86.23			78.08
W15-M	ALUM-Cu-1	68.220	70.600	69.440	69.420	1.192	1.720	ALUM-Cu-1	W15-M	69.42	84.11			69.42
W15-W	ALUM-Cu-1	256.600	267.400	273.300	265.800	8.440	3.180	ALUM-Cu-1	W15-W	265.80	332.15			265.80
W15-F	ALUM-Cu-1	92.420	92.880	94.310	93.200	0.984	1.060	ALUM-Cu-1	W15-F	93.20	128.40			93.20
W16-M	ALUM-Cu-1	65.640	67.890	67.950	67.160	1.315	1.960	ALUM-Cu-1	W16-M	67.16	119.28			67.16
W16-W	ALUM-Cu-1	50.620	43.230	41.770	45.210	4.748	10.500	ALUM-Cu-1	W16-W	45.21	199.11			45.21
W16-F	ALUM-Cu-1	56.150	59.380	61.680	59.070	2.777	4.700	ALUM-Cu-1	W16-F	59.07	129.64			59.07
W17-M	ALUM-Cu-1	51.080	41.430	41.880	44.800	5.444	12.150	ALUM-Cu-1	W17-M	44.80	67.02			44.80
W17-W	ALUM-Cu-1	38.020	37.590	36.360	37.320	0.858	2.300	ALUM-Cu-1	W17-W	37.32	48.10			37.32
W17-F	ALUM-Cu-1	22.620	33.010	25.020	26.880	5.439	20.230	ALUM-Cu-1	W17-F	26.88	40.28			26.88
W18-M	ALUM-Cu-1	37.990	29.430	43.120	36.850	6.914	18.760	ALUM-Cu-1	W18-M	36.85	55.34			36.85
W18-W	ALUM-Cu-1	30.760	37.660	40.940	0.455	5.195	14.250	ALUM-Cu-1	W18-W	0.45	34.38			0.45
W18-F	ALUM-Cu-1	25.670	23.800	21.250	23.570	2.217	9.410	ALUM-Cu-1	W18-F	23.57	35.45			23.57
W19-M	ALUM-Cu-1	40.790	37.930	37.350	38.690	1.844	4.770	ALUM-Cu-1	W19-M	38.69	53.19			38.69
W19-W	ALUM-Cu-1	37.980	34.700	35.560	36.080	1.701	4.720	ALUM-Cu-1	W19-W	36.08	48.40			36.08
W19-F	ALUM-Cu-1	38.510	38.670	38.410	38.530	0.133	0.340	ALUM-Cu-1	W19-F	38.53	50.00			38.53
W20-M	ALUM-Cu-1	41.420	40.390	41.170	40.990	0.535	1.300	ALUM-Cu-1	W20-M	40.99	60.15			40.99
W20-W	ALUM-Cu-1	53.370	51.070	52.740	52.400	1.190	2.270	ALUM-Cu-1	W20-W	52.40	70.35			52.40
W20-F	ALUM-Cu-1	40.880	38.820	39.690	39.800	1.032	2.590	ALUM-Cu-1	W20-F	39.80	51.61			39.80
W21-M	ALUM-Cu-1	34.310	36.890	33.590	34.930	1.736	4.970	ALUM-Cu-1	W21-M	34.93	52.01			34.93
W21-W	ALUM-Cu-1	37.900	36.860	36.950	37.240	0.574	1.540	ALUM-Cu-1	W21-W	37.24	52.96			37.24
W21-F	ALUM-Cu-1	35.170	34.070	32.120	33.790	1.544	4.570	ALUM-Cu-1	W21-F	33.79	45.57			33.79
W22-M	ALUM-Cu-1	4.880	3.760	4.210	4.283	0.564	13.160	ALUM-Cu-1	W22-M	4.28	27.82			4.28
W22-W	ALUM-Cu-1	53.830	54.880	52.590	53.770	1.149	2.140	ALUM-Cu-1	W22-W	53.77	60.15			53.77
W22-F	ALUM-Cu-1	37.180	34.930	30.690	34.270	3.295	9.610	ALUM-Cu-1	W22-F	34.27	44.33			34.27
W23-M	ALUM-Cu-1	50.490	41.490	46.430	46.140	4.511	9.780	ALUM-Cu-1	W23-M	46.14	59.77			46.14
W23-W	ALUM-Cu-1	30.420	29.460	30.170	30.020	0.495	1.650	ALUM-Cu-1	W23-W	30.02	41.89			30.02
W23-F	ALUM-Cu-1	30.940	30.900	27.740	29.860	1.837	6.150	ALUM-Cu-1	W23-F	29.86	38.60			29.86
W24-M	ALUM-Cu-1	46.520	53.280	55.460	51.750	4.663	9.010	ALUM-Cu-1	W24-M	51.75	53.29			51.75
W24-W	ALUM-Cu-1	50.990	48.970	51.060	50.340	1.187	2.360	ALUM-Cu-1	W24-W	50.34	56.84			50.34
W24-F	ALUM-Cu-1	47.180	41.740	38.740	42.550	4.282	10.060	ALUM-Cu-1	W24-F	42.55	45.17			42.55
W25-M	ALUM-Cu-1	48.900	45.680	46.940	47.170	1.623	3.440	ALUM-Cu-1	W25-M	47.17	49.38			47.17
W25-W	ALUM-Cu-1	54.230	55.110	55.110	54.810	0.508	0.930	ALUM-Cu-1	W25-W	54.81	65.47			54.81
W25-F	ALUM-Cu-1	20.470	22.850	21.640	21.650	1.189	5.490	ALUM-Cu-1	W25-F	21.65	22.54			21.65
W26-M	ALUM-Cu-1	41.070	40.250	41.180	40.830	0.511	1.250	ALUM-Cu-1	W26-M	40.83	28.89			40.83
W26-W	ALUM-Cu-1	26.320	28.710	28.690	27.910	1.373	4.920	ALUM-Cu-1	W26-W	27.91	20.82			27.91
W26-F	ALUM-Cu-1	55.770	51.440	51.020	52.740	2.631	4.990	ALUM-Cu-1	W26-F	52.74	52.74			52.74
W27-M	ALUM-Cu-1	55.690	56.830	54.870	55.800	0.982	1.760	ALUM-Cu-1	W27-M	55.80	40.55			55.80

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Cu-2	2422.000	2431.000	2356.000	2403.000	40.700	1.690	ALUM-Cu-2	W1-W	2403.00				2403.00
W1-F	ALUM-Cu-2	2313.000	2329.000	2404.000	2349.000	48.600	2.070	ALUM-Cu-2	W1-F	2349.00				2349.00
W2-M	ALUM-Cu-2	2170.000	2087.000	2107.000	2121.000	43.700	2.060	ALUM-Cu-2	W2-M	2121.00				2121.00
W2-W	ALUM-Cu-2	2020.000	2031.000	2017.000	2023.000	7.300	0.360	ALUM-Cu-2	W2-W	2023.00				2023.00
W2-F	ALUM-Cu-2	2423.000	1715.000	1601.000	1913.000	444.900	23.260	ALUM-Cu-2	W2-F	1913.00				1913.00
W3-M	ALUM-Cu-2	2734.000	1912.000	2341.000	2329.000	411.400	17.660	ALUM-Cu-2	W3-M	2329.00				2329.00
W3-W	ALUM-Cu-2	1742.000	1904.000	1937.000	1861.000	104.600	5.620	ALUM-Cu-2	W3-W	1861.00				1861.00
W3-F	ALUM-Cu-2	1674.000	1927.000	1495.000	1699.000	217.100	12.780	ALUM-Cu-2	W3-F	1699.00				1699.00
W4-M	ALUM-Cu-2	876.100	962.100	932.300	923.500	43.700	4.730	ALUM-Cu-2	W4-M	923.50				923.50
W4-W	ALUM-Cu-2	579.800	713.200	561.300	618.100	82.850	13.400	ALUM-Cu-2	W4-W	618.10				618.10
W4-F	ALUM-Cu-2	454.900	450.400	426.400	443.900	15.300	3.450	ALUM-Cu-2	W4-F	443.90				443.90
W5-M	ALUM-Cu-2	279.900	262.100	309.000	283.700	23.690	8.350	ALUM-Cu-2	W5-M	283.70				283.70
W5-W	ALUM-Cu-2	324.600	336.900	297.900	319.800	19.920	6.230	ALUM-Cu-2	W5-W	319.80				319.80
W5-F	ALUM-Cu-2	288.000	274.600	274.100	278.900	7.870	2.820	ALUM-Cu-2	W5-F	278.90				278.90
W6-M	ALUM-Cu-2	277.600	270.300	278.600	275.500	4.540	1.650	ALUM-Cu-2	W6-M	275.50				275.50
W6-W	ALUM-Cu-2	363.000	414.300	373.400	383.600	27.110	7.070	ALUM-Cu-2	W6-W	383.60				383.60
W6-F	ALUM-Cu-2	294.500	311.100	326.100	310.600	15.800	5.090	ALUM-Cu-2	W6-F	310.60				310.60
W7-M	ALUM-Cu-2	213.800	175.200	194.800	194.600	19.340	9.940	ALUM-Cu-2	W7-M	194.60				194.60
W7-W	ALUM-Cu-2	192.700	209.700	195.800	199.400	9.070	4.550	ALUM-Cu-2	W7-W	199.40				199.40
W7-F	ALUM-Cu-2	84.210	82.710	97.270	88.070	8.010	9.100	ALUM-Cu-2	W7-F	88.07				88.07
W8-M	ALUM-Cu-2	97.150	105.900	112.900	105.300	7.900	7.500	ALUM-Cu-2	W8-M	105.30				105.30
W8-W	ALUM-Cu-2	94.920	98.420	101.500	98.290	3.312	3.370	ALUM-Cu-2	W8-W	98.29				98.29
W8-F	ALUM-Cu-2	95.800	94.740	95.400	95.310	0.536	0.560	ALUM-Cu-2	W8-F	95.31				95.31
W9-M	ALUM-Cu-2	107.100	105.000	110.500	107.500	2.790	2.600	ALUM-Cu-2	W9-M	107.50				107.50
W9-W	ALUM-Cu-2	98.730	101.000	96.720	98.810	2.141	2.170	ALUM-Cu-2	W9-W	98.81				98.81
W9-F	ALUM-Cu-2	95.140	95.690	93.710	94.840	1.023	1.080	ALUM-Cu-2	W9-F	94.84				94.84
W10-M	ALUM-Cu-2	94.100	94.760	94.900	94.590	0.426	0.450	ALUM-Cu-2	W10-M	94.59				94.59
W10-W	ALUM-Cu-2	90.320	92.400	91.110	91.280	1.049	1.150	ALUM-Cu-2	W10-W	91.28				91.28
W10-F	ALUM-Cu-2	167.000	135.700	131.300	144.700	19.480	13.470	ALUM-Cu-2	W10-F	144.70				144.70
W11-M	ALUM-Cu-2	98.920	98.970	98.960	98.950	0.026	0.030	ALUM-Cu-2	W11-M	98.95				98.95
W11-W	ALUM-Cu-2	90.090	89.150	84.840	88.030	2.798	3.180	ALUM-Cu-2	W11-W	88.03				88.03
W11-F	ALUM-Cu-2	85.700	93.290	94.420	91.140	4.743	5.200	ALUM-Cu-2	W11-F	91.14				91.14
W12-M	ALUM-Cu-2	87.690	86.660	88.370	87.570	0.861	0.980	ALUM-Cu-2	W12-M	87.57				87.57
W12-W	ALUM-Cu-2	85.250	84.030	82.410	83.900	1.424	1.700	ALUM-Cu-2	W12-W	83.90				83.90
W12-F	ALUM-Cu-2	74.640	70.470	83.260	76.120	6.527	8.570	ALUM-Cu-2	W12-F	76.12				76.12
W13-M	ALUM-Cu-2	91.900	93.830	88.830	91.520	2.524	2.760	ALUM-Cu-2	W13-M	91.52				91.52
W13-W	ALUM-Cu-2	78.900	79.690	82.110	80.230	1.670	2.080	ALUM-Cu-2	W13-W	80.23				80.23
W13-F	ALUM-Cu-2	78.360	76.830	78.440	77.870	0.906	1.160	ALUM-Cu-2	W13-F	77.87				77.87
W14-M	ALUM-Cu-2	94.020	91.840	92.030	92.630	1.205	1.300	ALUM-Cu-2	W14-M	92.63				92.63
W14-W	ALUM-Cu-2	92.360	90.660	89.870	90.960	1.274	1.400	ALUM-Cu-2	W14-W	90.96				90.96
W14-F	ALUM-Cu-2	93.260	94.050	95.790	94.370	1.297	1.370	ALUM-Cu-2	W14-F	94.37				94.37
W15-M	ALUM-Cu-2	98.510	97.490	100.400	98.800	1.468	1.490	ALUM-Cu-2	W15-M	98.80				98.80
W15-W	ALUM-Cu-2	405.100	395.100	395.200	398.500	5.720	1.440	ALUM-Cu-2	W15-W	398.50				398.50
W15-F	ALUM-Cu-2	162.700	165.200	162.900	163.600	1.410	0.860	ALUM-Cu-2	W15-F	163.60				163.60
W16-M	ALUM-Cu-2	166.200	175.600	172.400	171.400	4.740	2.760	ALUM-Cu-2	W16-M	171.40				171.40
W16-W	ALUM-Cu-2	389.400	3.070	362.500	353.000	42.040	11.910	ALUM-Cu-2	W16-W	353.00				353.00
W16-F	ALUM-Cu-2	203.300	202.000	195.400	200.200	4.200	2.100	ALUM-Cu-2	W16-F	200.20				200.20
W17-M	ALUM-Cu-2	86.790	87.690	93.200	89.230	3.471	3.890	ALUM-Cu-2	W17-M	89.23				89.23
W17-W	ALUM-Cu-2	61.250	58.730	56.650	58.880	2.304	3.910	ALUM-Cu-2	W17-W	58.88				58.88
W17-F	ALUM-Cu-2	52.680	53.360	54.980	53.670	1.180	2.200	ALUM-Cu-2	W17-F	53.67				53.67
W18-M	ALUM-Cu-2	62.990	77.520	80.950	73.820	9.532	12.910	ALUM-Cu-2	W18-M	73.82				73.82
W18-W	ALUM-Cu-2	68.700	68.850	67.360	68.300	0.823	1.210	ALUM-Cu-2	W18-W	68.30				68.30
W18-F	ALUM-Cu-2	52.060	45.650	44.250	47.320	4.166	8.800	ALUM-Cu-2	W18-F	47.32				47.32
W19-M	ALUM-Cu-2	69.500	68.410	65.180	67.690	2.246	3.320	ALUM-Cu-2	W19-M	67.69				67.69
W19-W	ALUM-Cu-2	61.940	58.900	61.940	60.710	1.602	2.640	ALUM-Cu-2	W19-W	60.71				60.71
W19-F	ALUM-Cu-2	59.630	61.260	63.480	61.460	1.935	3.150	ALUM-Cu-2	W19-F	61.46				61.46
W20-M	ALUM-Cu-2	77.890	80.580	79.430	79.300	1.352	1.700	ALUM-Cu-2	W20-M	79.30				79.30
W20-W	ALUM-Cu-2	90.170	86.430	88.280	88.290	1.870	2.120	ALUM-Cu-2	W20-W	88.29				88.29
W20-F	ALUM-Cu-2	68.420	63.440	58.370	63.410	5.022	7.920	ALUM-Cu-2	W20-F	63.41				63.41
W21-M	ALUM-Cu-2	74.290	69.530	63.450	69.090	5.433	7.860	ALUM-Cu-2	W21-M	69.09				69.09
W21-W	ALUM-Cu-2	68.000	67.010	71.020	68.670	2.089	3.040	ALUM-Cu-2	W21-W	68.67				68.67
W21-F	ALUM-Cu-2	60.300	51.540	60.170	57.340	5.018	8.750	ALUM-Cu-2	W21-F	57.34				57.34
W22-M	ALUM-Cu-2	49.690	52.570	51.800	51.350	1.494	2.910	ALUM-Cu-2	W22-M	51.35				51.35
W22-W	ALUM-Cu-2	66.240	66.960	66.360	66.520	0.386	0.580	ALUM-Cu-2	W22-W	66.52				66.52
W22-F	ALUM-Cu-2	54.040	57.860	51.250	54.380	3.321	6.110	ALUM-Cu-2	W22-F	54.38				54.38
W23-M	ALUM-Cu-2	67.360	81.730	71.100	73.400	7.457	10.160	ALUM-Cu-2	W23-M	73.40				73.40
W23-W	ALUM-Cu-2	45.390	53.160	62.740	53.760	8.691	16.170	ALUM-Cu-2	W23-W	53.76				53.76
W23-F	ALUM-Cu-2	47.580	45.480	48.950	47.330	1.747	3.690	ALUM-Cu-2	W23-F	47.33				47.33
W24-M	ALUM-Cu-2	57.270	62.740	44.430	54.820	9.400	17.150	ALUM-Cu-2	W24-M	54.82				54.82
W24-W	ALUM-Cu-2	62.860	62.440	64.680	63.330	1.188	1.880	ALUM-Cu-2	W24-W	63.33				63.33
W24-F	ALUM-Cu-2	51.660	45.940	45.730	47.780	3.364	7.040	ALUM-Cu-2	W24-F	47.78				47.78
W25-M	ALUM-Cu-2	52.740	52.440	49.590	51.590	1.741	3.380	ALUM-Cu-2	W25-M	51.59				51.59
W25-W	ALUM-Cu-2	83.820	72.970	71.560	76.120	6.707	8.810	ALUM-Cu-2	W25-W	76.12				76.12
W25-F	ALUM-Cu-2	23.290	22.840	24.130	23.420	0.654	2.790	ALUM-Cu-2	W25-F	23.42				23.42
W26-M	ALUM-Cu-2	16.650	16.570	17.610	16.940	0.577	3.410	ALUM-Cu-2	W26-M	16.94				16.94
W26-W	ALUM-Cu-2	13.610	13.730	13.830	13.720	0.113	0.830	ALUM-Cu-2	W26-W	13.72				13.72
W26-F	ALUM-Cu-2	-	-	-	-	-	-	ALUM-Cu-2	W26-F	-				-
W27-M	ALUM-Cu-2	25.280	26.010	24.620	25.300	0.696	2.750	ALUM-Cu-2	W27-M	25.30				25.30

Week ID	Sample ID	Pb (Total) 1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Pb-1	7014.000	6926.000	6877.000	6939.000	69.700	1.010	ALUM-Pb-1	W1-W	6939.00	24174.50	W1	14793.75	6939.00
W1-F	ALUM-Pb-1	7122.000	7179.000	7235.000	7179.000	56.200	0.780	ALUM-Pb-1	W1-F	7179.00	5413.00	W2	2325.00	7179.00
W2-M	ALUM-Pb-1	1614.000	1336.000	1384.000	1445.000	148.600	10.280	ALUM-Pb-1	W2-M	1445.00	2388.50	W3	3211.67	1445.00
W2-W	ALUM-Pb-1	2406.000	2355.000	2035.000	2265.000	200.900	8.870	ALUM-Pb-1	W2-W	2265.00	2210.50	W4	2385.87	2265.00
W2-F	ALUM-Pb-1	1949.000	2318.000	2306.000	2191.000	209.400	9.560	ALUM-Pb-1	W2-F	2191.00	2376.00	W5	4438.35	2191.00
W3-M	ALUM-Pb-1	6824.000	7178.000	7286.000	7096.000	241.700	3.410	ALUM-Pb-1	W3-M	7096.00	4755.00	W6	1088.75	7096.00
W3-W	ALUM-Pb-1	2666.000	2803.000	2687.000	2718.000	73.700	2.710	ALUM-Pb-1	W3-W	2718.00	2790.00	W7	725.53	2718.00
W3-F	ALUM-Pb-1	1556.000	1517.000	1962.000	1678.000	246.100	14.660	ALUM-Pb-1	W3-F	1678.00	2090.00	W8	662.92	1678.00
W4-M	ALUM-Pb-1	1418.000	1429.000	1485.000	1444.000	36.000	2.490	ALUM-Pb-1	W4-M	1444.00	1246.00	W9	781.22	1444.00
W4-W	ALUM-Pb-1	954.300	841.900	867.300	887.800	58.920	6.640	ALUM-Pb-1	W4-W	887.80	1279.90	W10	709.02	887.80
W4-F	ALUM-Pb-1	696.800	831.200	660.100	729.400	90.060	12.350	ALUM-Pb-1	W4-F	729.40	4631.70	W11	1671.92	729.40
W5-M	ALUM-Pb-1	2164.000	2216.000	2291.000	2224.000	64.000	2.880	ALUM-Pb-1	W5-M	2224.00	8837.00	W12	275.28	2224.00
W5-W	ALUM-Pb-1	1431.000	1553.000	1762.000	1582.000	167.500	10.590	ALUM-Pb-1	W5-W	1582.00	2512.00	W13	269.25	1582.00
W5-F	ALUM-Pb-1	919.700	911.800	949.900	927.100	20.130	2.170	ALUM-Pb-1	W5-F	927.10	1966.05	W14	319.92	927.10
W6-M	ALUM-Pb-1	1187.000	1185.000	1191.000	1188.000	3.000	0.250	ALUM-Pb-1	W6-M	1188.00	1416.50	W15	839.20	1188.00
W6-W	ALUM-Pb-1	1191.000	1219.000	1200.000	1203.000	14.500	1.210	ALUM-Pb-1	W6-W	1203.00	1030.45	W16	394.37	1203.00
W6-F	ALUM-Pb-1	782.100	741.200	778.600	767.300	22.660	2.950	ALUM-Pb-1	W6-F	767.30	819.30	W17	271.44	767.30
W7-M	ALUM-Pb-1	725.400	700.600	705.600	710.500	13.080	1.840	ALUM-Pb-1	W7-M	710.50	751.40	W18	302.88	710.50
W7-W	ALUM-Pb-1	500.600	539.100	520.600	510.100	19.250	3.700	ALUM-Pb-1	W7-W	510.10	717.55	W19	289.47	510.10
W7-F	ALUM-Pb-1	665.800	699.600	676.400	680.600	17.250	2.530	ALUM-Pb-1	W7-F	680.60	707.65	W20	481.92	680.60
W8-M	ALUM-Pb-1	486.900	497.700	541.900	508.800	29.110	5.720	ALUM-Pb-1	W8-M	508.80	523.95	W21	354.21	508.80
W8-W	ALUM-Pb-1	-	-	-	-	-	-	ALUM-Pb-1	W8-W		1066.00	W22	492.47	-
W8-F	ALUM-Pb-1	90.730	98.750	107.200	98.910	8.259	8.350	ALUM-Pb-1	W8-F	98.91	398.81	W23	395.78	98.91
W9-M	ALUM-Pb-1	1302.000	1296.000	1318.000	1306.000	11.200	0.860	ALUM-Pb-1	W9-M	1306.00	1094.45	W24	683.53	1306.00
W9-W	ALUM-Pb-1	1018.000	1018.000	1026.000	1020.000	4.700	0.460	ALUM-Pb-1	W9-W	1020.00	764.55	W25	916.27	1020.00
W9-F	ALUM-Pb-1	678.100	615.200	614.200	635.800	36.640	36.640	ALUM-Pb-1	W9-F	635.80	484.65	W26	294.77	635.80
W10-M	ALUM-Pb-1	780.400	790.300	782.700	784.500	5.200	0.660	ALUM-Pb-1	W10-M	784.50	551.85	W27	335.55	784.50
W10-W	ALUM-Pb-1	201.200	185.200	186.900	191.100	8.780	4.590	ALUM-Pb-1	W10-W	191.10	269.50			191.10
W10-F	ALUM-Pb-1	1950.000	1711.000	1761.000	1807.000	126.300	6.990	ALUM-Pb-1	W10-F	1807.00	1305.70			1807.00
W11-M	ALUM-Pb-1	1569.000	1514.000	1516.000	1533.000	31.200	2.030	ALUM-Pb-1	W11-M	1533.00	1772.50			1533.00
W11-W	ALUM-Pb-1	3346.000	3202.000	3458.000	3335.000	128.400	3.850	ALUM-Pb-1	W11-W	3335.00	2515.50			3335.00
W11-F	ALUM-Pb-1	754.900	754.500	736.400	748.600	10.580	1.410	ALUM-Pb-1	W11-F	748.60	727.75			748.60
W12-M	ALUM-Pb-1	-	-	-	-	-	-	ALUM-Pb-1	W12-M		44.05			-
W12-W	ALUM-Pb-1	-	-	-	-	-	-	ALUM-Pb-1	W12-W		333.00			-
W12-F	ALUM-Pb-1	674.200	617.000	619.600	637.000	32.280	5.070	ALUM-Pb-1	W12-F	637.00	448.80			637.00
W13-M	ALUM-Pb-1	175.200	186.400	205.500	189.000	15.360	8.120	ALUM-Pb-1	W13-M	189.00	250.50			189.00
W13-W	ALUM-Pb-1	311.700	309.400	290.900	304.000	11.430	3.760	ALUM-Pb-1	W13-W	304.00	300.25			304.00
W13-F	ALUM-Pb-1	255.600	231.500	229.200	238.800	14.610	6.120	ALUM-Pb-1	W13-F	238.80	257.00			238.80
W14-M	ALUM-Pb-1	149.000	160.500	147.700	152.400	7.050	4.630	ALUM-Pb-1	W14-M	152.40	224.55			152.40
W14-W	ALUM-Pb-1	173.700	163.200	168.500	168.500	5.260	3.120	ALUM-Pb-1	W14-W	168.50	239.15			168.50
W14-F	ALUM-Pb-1	353.300	359.600	349.300	354.100	5.160	1.460	ALUM-Pb-1	W14-F	354.10	496.05			354.10
W15-M	ALUM-Pb-1	321.100	313.000	305.600	313.300	7.760	2.480	ALUM-Pb-1	W15-M	313.30	404.85			313.30
W15-W	ALUM-Pb-1	1634.000	1558.000	1533.000	1575.000	52.700	3.350	ALUM-Pb-1	W15-W	1575.00	1678.00			1575.00
W15-F	ALUM-Pb-1	339.200	301.900	301.800	314.300	21.550	6.860	ALUM-Pb-1	W15-F	314.30	434.75			314.30
W16-M	ALUM-Pb-1	290.000	307.400	296.300	297.900	8.780	2.950	ALUM-Pb-1	W16-M	297.90	398.50			297.90
W16-W	ALUM-Pb-1	206.300	371.200	278.300	285.300	82.670	28.980	ALUM-Pb-1	W16-W	285.30	384.80			285.30
W16-F	ALUM-Pb-1	284.700	300.300	297.700	294.200	8.340	2.840	ALUM-Pb-1	W16-F	294.20	399.80			294.20
W17-M	ALUM-Pb-1	314.100	304.600	306.900	30.860	4.970	1.610	ALUM-Pb-1	W17-M	30.86	237.08			30.86
W17-W	ALUM-Pb-1	119.300	135.900	121.600	125.600	8.960	7.130	ALUM-Pb-1	W17-W	125.60	189.50			125.60
W17-F	ALUM-Pb-1	310.700	337.500	262.700	303.600	37.920	12.490	ALUM-Pb-1	W17-F	303.60	387.75			303.60
W18-M	ALUM-Pb-1	238.200	229.100	224.000	230.400	7.230	3.140	ALUM-Pb-1	W18-M	230.40	357.55			230.40
W18-W	ALUM-Pb-1	192.000	234.900	226.000	217.600	22.650	10.410	ALUM-Pb-1	W18-W	217.60	331.55			217.60
W18-F	ALUM-Pb-1	182.500	175.300	165.300	174.400	8.652	4.940	ALUM-Pb-1	W18-F	174.40	219.55			174.40
W19-M	ALUM-Pb-1	196.900	204.500	277.900	226.400	44.700	19.740	ALUM-Pb-1	W19-M	226.40	274.00			226.40
W19-W	ALUM-Pb-1	239.100	232.500	237.000	236.200	3.360	1.420	ALUM-Pb-1	W19-W	236.20	278.75			236.20
W19-F	ALUM-Pb-1	229.400	150.100	231.500	203.700	46.400	22.780	ALUM-Pb-1	W19-F	203.70	315.65			203.70
W20-M	ALUM-Pb-1	217.500	212.100	216.000	215.200	2.780	1.290	ALUM-Pb-1	W20-M	215.20	328.05			215.20
W20-W	ALUM-Pb-1	275.400	275.500	259.700	270.200	9.110	3.370	ALUM-Pb-1	W20-W	270.20	545.95			270.20
W20-F	ALUM-Pb-1	266.300	269.800	281.100	272.400	7.710	2.830	ALUM-Pb-1	W20-F	272.40	571.75			272.40
W21-M	ALUM-Pb-1	255.800	268.000	288.600	270.800	16.560	6.120	ALUM-Pb-1	W21-M	270.80	480.50			270.80
W21-W	ALUM-Pb-1	269.900	299.000	306.700	292.000	19.490	6.670	ALUM-Pb-1	W21-W	292.00	368.85			292.00
W21-F	ALUM-Pb-1	87.620	111.900	95.620	98.380	12.366	12.570	ALUM-Pb-1	W21-F	98.38	213.29			98.38
W22-M	ALUM-Pb-1	677.100	686.800	754.100	706.000	41.930	5.940	ALUM-Pb-1	W22-M	706.00	721.55			706.00
W22-W	ALUM-Pb-1	293.600	297.500	314.700	301.900	11.240	3.720	ALUM-Pb-1	W22-W	301.90	410.55			301.90
W22-F	ALUM-Pb-1	260.400	267.800	257.200	261.800	5.470	2.090	ALUM-Pb-1	W22-F	261.80	345.30			261.80
W23-M	ALUM-Pb-1	273.000	282.500	280.800	278.800	5.050	1.810	ALUM-Pb-1	W23-M	278.80	366.45			278.80
W23-W	ALUM-Pb-1	310.900	297.600	296.900	301.800	7.890	2.620	ALUM-Pb-1	W23-W	301.80	403.95			301.80
W23-F	ALUM-Pb-1	316.900	317.700	302.400	312.300	8.620	2.760	ALUM-Pb-1	W23-F	312.30	416.95			312.30
W24-M	ALUM-Pb-1	-	-	-	-	-	-	ALUM-Pb-1	W24-M		341.70			-
W24-W	ALUM-Pb-1	1425.000	1315.000	1525.000	1422.000	104.800	7.370	ALUM-Pb-1	W24-W	1422.00	960.45			1422.00
W24-F	ALUM-Pb-1	1036.000	1039.000	1084.000	1053.000	26.900	2.550	ALUM-Pb-1	W24-F	1053.00	748.45			1053.00
W25-M	ALUM-Pb-1	598.600	601.100	625.100	608.300	14.650	2.410	ALUM-Pb-1	W25-M	608.30	578.60			608.30
W25-W	ALUM-Pb-1	1853.000	1897.000	1900.000	1883.000	26.200	1.390	ALUM-Pb-1	W25-W	1883.00	1883.00			1883.00
W25-F	ALUM-Pb-1	488.600	327.000	365.900	393.900	84.340	21.410	ALUM-Pb-1	W25-F	393.90	287.20			393.90
W26-M	ALUM-Pb-1	242.600	263.000	233.000	246.200	15.350	6.230	ALUM-Pb-1	W26-M	246.20	254.65			246.20
W26-W	ALUM-Pb-1	263.000	269.400	253.800	262.100	7.860	3.000	ALUM-Pb-1	W26-W	262.10	246.95			262.10
W26-F	ALUM-Pb-1	244.700	285.700	303.000	277.800	29.950	10.780	ALUM-Pb-1	W26-F	277.80	382.70			277.80
W27-M	ALUM-Pb-1	250.000	224.400	318.300	264.200	48.540	18.370	ALUM-Pb-1	W27-M	264.20	335.55			264.20

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Pb-2	39730.000	43230.000	41280.000	41410.000	1757.400	4.240	ALUM-Pb-2	W1-W	41410.00				41410.00
W1-F	ALUM-Pb-2	3587.000	3609.000	3745.000	3647.000	85.400	2.340	ALUM-Pb-2	W1-F	3647.00				3647.00
W2-M	ALUM-Pb-2	3235.000	3395.000	3366.000	3332.000	85.400	2.560	ALUM-Pb-2	W2-M	3332.00				3332.00
W2-W	ALUM-Pb-2	2236.000	2247.000	2010.000	2156.000	133.800	6.180	ALUM-Pb-2	W2-W	2156.00				2156.00
W2-F	ALUM-Pb-2	2136.000	2439.000	3108.000	2561.000	497.400	19.430	ALUM-Pb-2	W2-F	2561.00				2561.00
W3-M	ALUM-Pb-2	2211.000	2608.000	2422.000	2414.000	198.700	8.230	ALUM-Pb-2	W3-M	2414.00				2414.00
W3-W	ALUM-Pb-2	2866.000	2872.000	2848.000	2862.000	12.400	0.430	ALUM-Pb-2	W3-W	2862.00				2862.00
W3-F	ALUM-Pb-2	2406.000	2730.000	2369.000	2502.000	198.400	7.930	ALUM-Pb-2	W3-F	2502.00				2502.00
W4-M	ALUM-Pb-2	928.400	1073.000	1143.000	1048.000	109.300	10.430	ALUM-Pb-2	W4-M	1048.00				1048.00
W4-W	ALUM-Pb-2	1714.000	1660.000	1642.000	1672.000	37.800	2.260	ALUM-Pb-2	W4-W	1672.00				1672.00
W4-F	ALUM-Pb-2	8559.000	8487.000	8557.000	8534.000	40.700	0.480	ALUM-Pb-2	W4-F	8534.00				8534.00
W5-M	ALUM-Pb-2	15580.000	15410.000	15380.000	15450.000	106.500	0.690	ALUM-Pb-2	W5-M	15450.00				15450.00
W5-W	ALUM-Pb-2	3220.000	3826.000	3279.000	3442.000	334.000	9.700	ALUM-Pb-2	W5-W	3442.00				3442.00
W5-F	ALUM-Pb-2	3049.000	2971.000	2994.000	3005.000	39.700	1.320	ALUM-Pb-2	W5-F	3005.00				3005.00
W6-M	ALUM-Pb-2	1647.000	1651.000	1635.000	1645.000	8.300	0.510	ALUM-Pb-2	W6-M	1645.00				1645.00
W6-W	ALUM-Pb-2	871.300	859.700	842.600	857.900	14.440	1.680	ALUM-Pb-2	W6-W	857.90				857.90
W6-F	ALUM-Pb-2	854.700	900.800	858.400	871.300	25.610	2.940	ALUM-Pb-2	W6-F	871.30				871.30
W7-M	ALUM-Pb-2	797.800	797.500	781.600	792.300	9.270	1.170	ALUM-Pb-2	W7-M	792.30				792.30
W7-W	ALUM-Pb-2	752.500	990.700	1032.000	925.000	150.780	16.300	ALUM-Pb-2	W7-W	925.00				925.00
W7-F	ALUM-Pb-2	748.100	725.200	730.900	734.700	11.930	1.620	ALUM-Pb-2	W7-F	734.70				734.70
W8-M	ALUM-Pb-2	547.100	533.900	536.300	539.100	7.000	1.300	ALUM-Pb-2	W8-M	539.10				539.10
W8-W	ALUM-Pb-2	1008.000	1097.000	1093.000	1066.000	50.000	4.690	ALUM-Pb-2	W8-W	1066.00				1066.00
W8-F	ALUM-Pb-2	675.900	717.100	703.100	698.700	20.960	3.000	ALUM-Pb-2	W8-F	698.70				698.70
W9-M	ALUM-Pb-2	885.000	880.600	883.000	882.900	2.170	0.250	ALUM-Pb-2	W9-M	882.90				882.90
W9-W	ALUM-Pb-2	502.800	508.900	515.400	509.100	6.320	1.240	ALUM-Pb-2	W9-W	509.10				509.10
W9-F	ALUM-Pb-2	383.700	289.500	327.400	333.500	47.410	14.210	ALUM-Pb-2	W9-F	333.50				333.50
W10-M	ALUM-Pb-2	316.300	315.500	325.500	319.200	5.410	1.690	ALUM-Pb-2	W10-M	319.20				319.20
W10-W	ALUM-Pb-2	315.400	368.700	359.600	347.900	28.510	8.190	ALUM-Pb-2	W10-W	347.90				347.90
W10-F	ALUM-Pb-2	838.900	805.800	768.400	804.400	35.240	4.380	ALUM-Pb-2	W10-F	804.40				804.40
W11-M	ALUM-Pb-2	1920.000	2070.000	2045.000	2012.000	80.300	3.990	ALUM-Pb-2	W11-M	2012.00				2012.00
W11-W	ALUM-Pb-2	1656.000	1723.000	1710.000	1696.000	35.500	2.090	ALUM-Pb-2	W11-W	1696.00				1696.00
W11-F	ALUM-Pb-2	665.000	681.500	774.100	706.900	58.820	8.320	ALUM-Pb-2	W11-F	706.90				706.90
W12-M	ALUM-Pb-2	59.740	38.100	34.300	44.050	13.724	31.160	ALUM-Pb-2	W12-M	44.05				44.05
W12-W	ALUM-Pb-2	306.400	352.700	339.900	333.000	23.890	7.170	ALUM-Pb-2	W12-W	333.00				333.00
W12-F	ALUM-Pb-2	271.800	252.400	257.600	260.600	10.020	3.850	ALUM-Pb-2	W12-F	260.60				260.60
W13-M	ALUM-Pb-2	298.800	326.800	310.300	312.000	14.100	4.520	ALUM-Pb-2	W13-M	312.00				312.00
W13-W	ALUM-Pb-2	306.700	301.700	281.100	296.500	13.560	4.570	ALUM-Pb-2	W13-W	296.50				296.50
W13-F	ALUM-Pb-2	321.400	231.800	272.400	275.200	44.830	16.290	ALUM-Pb-2	W13-F	275.20				275.20
W14-M	ALUM-Pb-2	297.900	292.200	300.100	296.700	4.070	1.370	ALUM-Pb-2	W14-M	296.70				296.70
W14-W	ALUM-Pb-2	310.600	317.500	301.400	309.800	8.090	2.610	ALUM-Pb-2	W14-W	309.80				309.80
W14-F	ALUM-Pb-2	662.500	619.800	631.700	638.000	22.020	3.450	ALUM-Pb-2	W14-F	638.00				638.00
W15-M	ALUM-Pb-2	476.900	521.900	490.400	496.400	23.110	4.660	ALUM-Pb-2	W15-M	496.40				496.40
W15-W	ALUM-Pb-2	1754.000	1800.000	1789.000	1781.000	24.100	1.360	ALUM-Pb-2	W15-W	1781.00				1781.00
W15-F	ALUM-Pb-2	562.700	556.400	546.500	555.200	8.160	1.470	ALUM-Pb-2	W15-F	555.20				555.20
W16-M	ALUM-Pb-2	508.200	492.800	496.300	499.100	8.080	1.620	ALUM-Pb-2	W16-M	499.10				499.10
W16-W	ALUM-Pb-2	455.800	545.500	451.600	484.300	53.080	10.960	ALUM-Pb-2	W16-W	484.30				484.30
W16-F	ALUM-Pb-2	517.400	502.400	496.300	505.400	10.860	2.150	ALUM-Pb-2	W16-F	505.40				505.40
W17-M	ALUM-Pb-2	474.100	420.700	435.200	443.300	27.620	6.230	ALUM-Pb-2	W17-M	443.30				443.30
W17-W	ALUM-Pb-2	243.000	254.300	262.800	253.400	9.970	3.930	ALUM-Pb-2	W17-W	253.40				253.40
W17-F	ALUM-Pb-2	472.900	442.800	500.000	471.900	28.570	6.060	ALUM-Pb-2	W17-F	471.90				471.90
W18-M	ALUM-Pb-2	530.700	448.600	474.800	484.700	41.920	8.650	ALUM-Pb-2	W18-M	484.70				484.70
W18-W	ALUM-Pb-2	470.400	433.100	433.000	445.500	21.590	4.850	ALUM-Pb-2	W18-W	445.50				445.50
W18-F	ALUM-Pb-2	269.300	258.500	266.300	264.700	5.570	2.100	ALUM-Pb-2	W18-F	264.70				264.70
W19-M	ALUM-Pb-2	328.100	313.400	323.400	321.600	7.510	2.330	ALUM-Pb-2	W19-M	321.60				321.60
W19-W	ALUM-Pb-2	319.400	327.400	317.100	321.300	5.410	1.680	ALUM-Pb-2	W19-W	321.30				321.30
W19-F	ALUM-Pb-2	449.800	420.700	412.500	427.600	19.610	4.590	ALUM-Pb-2	W19-F	427.60				427.60
W20-M	ALUM-Pb-2	447.100	446.600	429.100	440.900	10.260	2.330	ALUM-Pb-2	W20-M	440.90				440.90
W20-W	ALUM-Pb-2	814.400	815.400	835.000	821.700	11.570	1.410	ALUM-Pb-2	W20-W	821.70				821.70
W20-F	ALUM-Pb-2	859.500	886.100	867.800	871.100	13.610	1.560	ALUM-Pb-2	W20-F	871.10				871.10
W21-M	ALUM-Pb-2	699.700	692.200	678.500	690.200	10.770	1.560	ALUM-Pb-2	W21-M	690.20				690.20
W21-W	ALUM-Pb-2	432.000	451.100	454.000	445.700	11.920	2.680	ALUM-Pb-2	W21-W	445.70				445.70
W21-F	ALUM-Pb-2	331.800	325.800	327.100	328.200	3.190	0.970	ALUM-Pb-2	W21-F	328.20				328.20
W22-M	ALUM-Pb-2	714.900	757.100	739.400	737.100	21.190	2.880	ALUM-Pb-2	W22-M	737.10				737.10
W22-W	ALUM-Pb-2	498.000	534.700	525.000	519.200	18.980	3.650	ALUM-Pb-2	W22-W	519.20				519.20
W22-F	ALUM-Pb-2	438.300	436.500	411.600	428.800	14.900	3.470	ALUM-Pb-2	W22-F	428.80				428.80
W23-M	ALUM-Pb-2	463.000	452.400	447.000	454.100	8.150	1.800	ALUM-Pb-2	W23-M	454.10				454.10
W23-W	ALUM-Pb-2	492.800	509.200	516.500	506.100	12.140	2.400	ALUM-Pb-2	W23-W	506.10				506.10
W23-F	ALUM-Pb-2	532.200	517.800	514.700	521.600	9.300	1.780	ALUM-Pb-2	W23-F	521.60				521.60
W24-M	ALUM-Pb-2	349.300	309.300	366.400	341.700	29.310	8.580	ALUM-Pb-2	W24-M	341.70				341.70
W24-W	ALUM-Pb-2	510.800	481.500	504.400	498.900	15.380	3.080	ALUM-Pb-2	W24-W	498.90				498.90
W24-F	ALUM-Pb-2	503.700	471.000	356.900	443.900	77.090	17.370	ALUM-Pb-2	W24-F	443.90				443.90
W25-M	ALUM-Pb-2	574.300	554.500	518.000	548.900	28.560	5.200	ALUM-Pb-2	W25-M	548.90				548.90
W25-W	ALUM-Pb-2	-	-	-	-	-	-	ALUM-Pb-2	W25-W					
W25-F	ALUM-Pb-2	196.200	166.700	178.600	180.500	14.840	8.220	ALUM-Pb-2	W25-F	180.50				180.50
W26-M	ALUM-Pb-2	266.700	269.100	25.400	263.100	8.470	3.220	ALUM-Pb-2	W26-M	263.10				263.10
W26-W	ALUM-Pb-2	241.800	235.800	217.700	231.800	12.530	5.410	ALUM-Pb-2	W26-W	231.80				231.80
W26-F	ALUM-Pb-2	583.000	376.500	503.200	487.600	104.140	21.360	ALUM-Pb-2	W26-F	487.60				487.60
W27-M	ALUM-Pb-2	415.000	361.000	444.700	406.900	42.470	10.440	ALUM-Pb-2	W27-M	406.90				406.90

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Cu-1	7099.000	7330.000	7103.000	7178.000	132.300	1.840	FS-Cu-1	W1-W	7178.00	5209.50	W1	3790.50	7178.00
W1-F	FS-Cu-1	2484.000	2341.000	2401.000	2409.000	71.900	2.980	FS-Cu-1	W1-F	2409.00	2371.50	W2	1986.00	2409.00
W2-M	FS-Cu-1	2148.000	1820.000	1950.000	1972.000	165.100	8.370	FS-Cu-1	W2-M	1972.00	2189.50	W3	2196.25	1972.00
W2-W	FS-Cu-1-Comp	-	-	-	-	-	-	FS-Cu-1-Comp	W2-W			W4	702.75	-
W2-F	FS-Cu-1	2058.000	1913.000	983.200	1652.000	583.300	35.320	FS-Cu-1	W2-F	1652.00	1782.50	W5	248.47	1652.00
W3-M	FS-Cu-1	2420.000	2544.000	2335.000	2433.000	104.800	4.310	FS-Cu-1	W3-M	2433.00	2644.00	W6	278.97	2433.00
W3-W	FS-Cu-1	2391.000	2364.000	2378.000	2377.000	13.500	0.570	FS-Cu-1	W3-W	2377.00	2746.00	W7	277.50	2377.00
W3-F	FS-Cu-1	671.300	375.300	931.900	659.500	278.480	42.220	FS-Cu-1	W3-F	659.50	1198.75	W8	238.73	659.50
W4-M	FS-Cu-1	1035.000	975.100	1061.000	1024.000	44.000	4.300	FS-Cu-1	W4-M	1024.00	1283.50	W9	206.93	1024.00
W4-W	FS-Cu-1	364.000	355.300	313.700	344.400	26.880	7.810	FS-Cu-1	W4-W	344.40	538.35	W10	183.10	344.40
W4-F	FS-Cu-1							FS-Cu-1	W4-F	0.00	286.40	W11	140.38	0.00
W5-M	FS-Cu-1	290.300	242.300	252.900	261.800	25.220	9.630	FS-Cu-1	W5-M	261.80	377.50	W12	68.78	261.80
W5-W	FS-Cu-1	185.600	130.000	124.900	146.900	33.660	22.920	FS-Cu-1	W5-W	146.90	221.90	W13	91.15	146.90
W5-F	FS-Cu-1	137.200	98.380	78.260	104.600	29.950	28.630	FS-Cu-1	W5-F	104.60	146.00	W14	104.75	104.60
W6-M	FS-Cu-1	162.200	110.200	108.200	126.900	30.600	24.120	FS-Cu-1	W6-M	126.90	196.40	W15	338.13	126.90
W6-W	FS-Cu-1	233.200	175.700	153.100	187.400	41.300	22.040	FS-Cu-1	W6-W	187.40	274.85	W16	66.22	187.40
W6-F	FS-Cu-1	298.400	207.300	205.800	237.100	53.040	22.370	FS-Cu-1	W6-F	237.10	365.65	W17	34.69	237.10
W7-M	FS-Cu-1	226.200	152.300	153.800	177.400	42.260	23.810	FS-Cu-1	W7-M	177.40	317.85	W18	43.11	177.40
W7-W	FS-Cu-1	205.900	145.500	142.400	164.600	35.790	21.740	FS-Cu-1	W7-W	164.60	258.20	W19	43.30	164.60
W7-F	FS-Cu-1	216.000	175.800	163.500	185.100	27.460	14.840	FS-Cu-1	W7-F	185.10	256.45	W20	36.70	185.10
W8-M	FS-Cu-1	181.900	176.200	183.200	180.400	3.710	2.050	FS-Cu-1	W8-M	180.40	276.45	W21	45.46	180.40
W8-W	FS-Cu-1	154.000	160.200	160.000	158.100	3.520	2.220	FS-Cu-1	W8-W	158.10	188.40	W22	34.89	158.10
W8-F	FS-Cu-1	203.300	210.800	212.200	208.800	4.830	2.310	FS-Cu-1	W8-F	208.80	251.35	W23	17.51	208.80
W9-M	FS-Cu-1	101.800	118.800	116.600	112.400	9.260	8.230	FS-Cu-1	W9-M	112.40	245.55	W24	10.80	112.40
W9-W	FS-Cu-1	95.850	97.330	113.600	102.200	9.830	9.610	FS-Cu-1	W9-W	102.20	191.35	W25	7.79	102.20
W9-F	FS-Cu-1	86.340	87.660	90.220	88.070	1.973	2.240	FS-Cu-1	W9-F	88.07	183.89	W26	6.44	88.07
W10-M	FS-Cu-1	91.700	94.320	0.260	94.760	3.304	3.490	FS-Cu-1	W10-M	94.76	216.38	W27	20.14	94.76
W10-W	FS-Cu-1	75.770	75.100	75.870	75.580	0.419	0.550	FS-Cu-1	W10-W	75.58	184.19			75.58
W10-F	FS-Cu-1	80.800	94.040	99.440	91.430	9.593	10.490	FS-Cu-1	W10-F	91.43	148.72			91.43
W11-M	FS-Cu-1	124.800	154.100	135.600	138.200	14.780	10.700	FS-Cu-1	W11-M	138.20	168.90			138.20
W11-W	FS-Cu-1	66.080	65.740	75.690	69.170	5.648	8.160	FS-Cu-1	W11-W	69.17	128.54			69.17
W11-F	FS-Cu-1	70.980	63.650	70.870	68.500	4.202	6.130	FS-Cu-1	W11-F	68.50	123.70			68.50
W12-M	FS-Cu-1	75.000	70.940	77.520	74.490	3.317	4.450	FS-Cu-1	W12-M	74.49	92.65			74.49
W12-W	FS-Cu-1	56.630	56.400	56.620	56.550	0.131	0.230	FS-Cu-1	W12-W	56.55	80.48			56.55
W12-F	FS-Cu-1	11.330	8.807	7.718	9.284	1.852	19.940	FS-Cu-1	W12-F	9.28	33.22			9.28
W13-M	FS-Cu-1	77.270	85.430	78.970	80.560	4.302	5.340	FS-Cu-1	W13-M	80.56	124.58			80.56
W13-W	FS-Cu-1	48.230	50.600	49.420	49.420	1.185	2.400	FS-Cu-1	W13-W	49.42	73.77			49.42
W13-F	FS-Cu-1	50.170	49.440	49.420	49.680	0.429	0.860	FS-Cu-1	W13-F	49.68	75.09			49.68
W14-M	FS-Cu-1	44.480	44.510	43.150	44.040	0.775	1.760	FS-Cu-1	W14-M	44.04	92.82			44.04
W14-W	FS-Cu-1	46.090	45.350	45.470	45.640	0.400	0.880	FS-Cu-1	W14-W	45.64	115.92			45.64
W14-F	FS-Cu-1	44.280	42.960	42.710	43.320	0.844	1.950	FS-Cu-1	W14-F	43.32	105.51			43.32
W15-M	FS-Cu-1	44.280	42.960	42.710	43.320	0.844	1.950	FS-Cu-1	W15-M	43.32	860.16			43.32
W15-W	FS-Cu-1	32.090	28.730	30.010	30.270	1.696	5.600	FS-Cu-1	W15-W	30.27	88.49			30.27
W15-F	FS-Cu-1	27.870	25.300	19.590	24.260	4.239	17.480	FS-Cu-1	W15-F	24.26	65.73			24.26
W16-M	FS-Cu-1	42.750	40.400	40.770	41.310	1.263	3.060	FS-Cu-1	W16-M	41.31	97.51			41.31
W16-W	FS-Cu-1	18.130	18.700	19.370	18.730	0.622	3.320	FS-Cu-1	W16-W	18.73	56.94			18.73
W16-F	FS-Cu-1	17.800	13.990	11.330	14.370	3.254	22.640	FS-Cu-1	W16-F	14.37	44.21			14.37
W17-M	FS-Cu-1	5.333	4.735	4.130	4.732	0.602	12.710	FS-Cu-1	W17-M	4.73	33.24			4.73
W17-W	FS-Cu-1	2.494	1.667	2.141	2.101	0.415	19.750	FS-Cu-1	W17-W	2.10	35.00			2.10
W17-F	FS-Cu-1	7.549	8.741	7.480	7.924	0.709	8.940	FS-Cu-1	W17-F	7.92	35.82			7.92
W18-M	FS-Cu-1	9.314	10.810	10.560	10.230	0.801	7.830	FS-Cu-1	W18-M	10.23	44.62			10.23
W18-W	FS-Cu-1	24.210	24.560	24.830	24.530	0.311	1.270	FS-Cu-1	W18-W	24.53	44.41			24.53
W18-F	FS-Cu-1	1.817	1.864	-0.699	0.994	1.466	147.510	FS-Cu-1	W18-F	0.99	40.32			0.99
W19-M	FS-Cu-1	16.580	10.500	11.660	12.910	3.229	25.010	FS-Cu-1	W19-M	12.91	47.10			12.91
W19-W	FS-Cu-1	13.930	9.040	7.743	10.240	3.260	31.850	FS-Cu-1	W19-W	10.24	44.80			10.24
W19-F	FS-Cu-1	2.346	0.885	2.124	1.785	0.788	44.120	FS-Cu-1	W19-F	1.79	38.02			1.79
W20-M	FS-Cu-1	8.491	6.691	7.135	7.439	0.938	12.610	FS-Cu-1	W20-M	7.44	41.80			7.44
W20-W	FS-Cu-1	7.800	6.583	3.665	6.016	2.125	35.320	FS-Cu-1	W20-W	6.02	38.88			6.02
W20-F	FS-Cu-1	6.502	4.853	5.119	5.491	0.885	16.120	FS-Cu-1	W20-F	5.49	29.41			5.49
W21-M	FS-Cu-1	12.960	11.030	10.640	11.540	1.240	10.750	FS-Cu-1	W21-M	11.54	38.91			11.54
W21-W	FS-Cu-1	56.550	60.920	58.570	58.680	2.185	3.720	FS-Cu-1	W21-W	58.68	53.95			58.68
W21-F	FS-Cu-1	41.130	41.630	43.980	42.250	1.523	3.610	FS-Cu-1	W21-F	42.25	43.52			42.25
W22-M	FS-Cu-1	36.370	37.110	33.530	35.840	2.006	5.600	FS-Cu-1	W22-M	35.84	47.45			35.84
W22-W	FS-Cu-1	4.791	2.923	2.748	3.487	1.132	32.460	FS-Cu-1	W22-W	3.49	29.83			3.49
W22-F	FS-Cu-1	4.789	1.951	1.249	2.663	1.874	70.380	FS-Cu-1	W22-F	2.66	27.39			2.66
W23-M	FS-Cu-1	3.350	4.218	2.962	3.510	0.644	18.330	FS-Cu-1	W23-M	3.51	20.87			3.51
W23-W	FS-Cu-1	2.145	4.206	0.979	2.444	1.634	66.880	FS-Cu-1	W23-W	2.44	19.10			2.44
W23-F	FS-Cu-1	0.064	-1.426	-1.130	-0.831	0.789	94.960	FS-Cu-1	W23-F	0.00	12.56			-0.83
W24-M	FS-Cu-1	3.786	4.110	4.498	4.131	0.357	8.630	FS-Cu-1	W24-M	4.13	9.41			4.13
W24-W	FS-Cu-1	-3.110	-3.906	-0.837	-2.618	1.593	60.840	FS-Cu-1	W24-W	0.00	13.65			-2.62
W24-F	FS-Cu-1	-2.572	-3.606	-3.867	-3.348	0.685	20.450	FS-Cu-1	W24-F	0.00	9.36			-3.35
W25-M	FS-Cu-1	1.720	1.081	1.133	1.311	0.355	27.100	FS-Cu-1	W25-M	1.31	11.93			1.31
W25-W	FS-Cu-1	-1.331	-1.959	-2.300	-1.863	0.492	26.370	FS-Cu-1	W25-W	0.00	8.93			-1.86
W25-F	FS-Cu-1	-4.981	-4.339	-5.202	-4.841	0.449	9.270	FS-Cu-1	W25-F	0.00	2.51			-4.84
W26-M	FS-Cu-1	-3.752	-4.499	-4.615	-4.289	0.469	10.930	FS-Cu-1	W26-M	0.00	3.49			-4.29
W26-W	FS-Cu-1	-3.629	-3.829	-4.039	-3.832	0.205	5.340	FS-Cu-1	W26-W	0.00	2.84			-3.83
W26-F	FS-Cu-1	6.272	4.899	3.638	4.936	1.318	26.690	FS-Cu-1	W26-F	4.94	13.00			4.94
W27-M	FS-Cu-1	10.450	8.264	7.260	8.657	1.629	18.810	FS-Cu-1	W27-M	8.66	20.14			8.66

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Cu-2	3328.000	3222.000	3174.000	3241.000	79.000	2.440	FS-Cu-2	W1-W	3241.00				3241.00
W1-F	FS-Cu-2	2412.000	2347.000	2244.000	2334.000	85.200	3.650	FS-Cu-2	W1-F	2334.00				2334.00
W2-M	FS-Cu-2	2516.000	2221.000	2485.000	2407.000	162.100	6.730	FS-Cu-2	W2-M	2407.00				2407.00
W2-W	FS-Cu-2-Comp	-	-	-	-	-	-	FS-Cu-2-Comp	W2-W					-
W2-F	FS-Cu-2	2272.000	1935.000	1532.000	1913.000	370.700	19.370	FS-Cu-2	W2-F	1913.00				1913.00
W3-M	FS-Cu-2	3146.000	2537.000	2881.000	2855.000	305.200	10.690	FS-Cu-2	W3-M	2855.00				2855.00
W3-W	FS-Cu-2	3158.000	3205.000	2981.000	3115.000	118.200	3.800	FS-Cu-2	W3-W	3115.00				3115.00
W3-F	FS-Cu-2	1849.000	1642.000	1723.000	1738.000	104.300	6.000	FS-Cu-2	W3-F	1738.00				1738.00
W4-M	FS-Cu-2	1441.000	1582.000	1606.000	1543.000	89.500	5.800	FS-Cu-2	W4-M	1543.00				1543.00
W4-W	FS-Cu-2	740.100	731.000	725.700	732.300	7.320	1.000	FS-Cu-2	W4-W	732.30				732.30
W4-F	FS-Cu-2	583.100	572.100	563.100	572.800	10.010	1.750	FS-Cu-2	W4-F	572.80				572.80
W5-M	FS-Cu-2	484.600	472.000	523.000	493.200	26.560	5.390	FS-Cu-2	W5-M	493.20				493.20
W5-W	FS-Cu-2	287.200	298.700	304.800	296.900	8.930	3.010	FS-Cu-2	W5-W	296.90				296.90
W5-F	FS-Cu-2	244.200	158.600	159.200	187.400	49.260	26.290	FS-Cu-2	W5-F	187.40				187.40
W6-M	FS-Cu-2	253.700	276.900	267.000	265.900	11.640	4.380	FS-Cu-2	W6-M	265.90				265.90
W6-W	FS-Cu-2	381.600	359.300	346.200	362.300	17.910	4.940	FS-Cu-2	W6-W	362.30				362.30
W6-F	FS-Cu-2	493.600	487.300	501.700	494.200	7.240	1.460	FS-Cu-2	W6-F	494.20				494.20
W7-M	FS-Cu-2	455.600	469.000	450.500	458.300	9.560	2.080	FS-Cu-2	W7-M	458.30				458.30
W7-W	FS-Cu-2	393.200	343.800	318.400	351.800	38.070	10.820	FS-Cu-2	W7-W	351.80				351.80
W7-F	FS-Cu-2	298.900	327.300	357.800	327.800	29.240	8.920	FS-Cu-2	W7-F	327.80				327.80
W8-M	FS-Cu-2	395.500	349.900	372.000	372.500	22.820	6.130	FS-Cu-2	W8-M	372.50				372.50
W8-W	FS-Cu-2	215.700	215.300	225.200	218.700	5.580	2.550	FS-Cu-2	W8-W	218.70				218.70
W8-F	FS-Cu-2	294.500	317.500	269.600	293.900	23.980	8.160	FS-Cu-2	W8-F	293.90				293.90
W9-M	FS-Cu-2	382.100	380.000	374.200	378.700	4.080	1.080	FS-Cu-2	W9-M	378.70				378.70
W9-W	FS-Cu-2	290.800	273.500	277.100	280.500	9.130	3.260	FS-Cu-2	W9-W	280.50				280.50
W9-F	FS-Cu-2	277.200	287.400	274.400	279.700	6.850	2.450	FS-Cu-2	W9-F	279.70				279.70
W10-M	FS-Cu-2	362.800	329.500	321.800	338.000	21.800	6.450	FS-Cu-2	W10-M	338.00				338.00
W10-W	FS-Cu-2	315.900	279.100	283.400	292.800	20.100	6.870	FS-Cu-2	W10-W	292.80				292.80
W10-F	FS-Cu-2	214.200	195.500	208.100	206.000	9.610	4.670	FS-Cu-2	W10-F	206.00				206.00
W11-M	FS-Cu-2	205.900	1889.600	203.400	199.600	8.780	4.400	FS-Cu-2	W11-M	199.60				199.60
W11-W	FS-Cu-2	168.000	204.500	191.000	187.900	18.460	9.830	FS-Cu-2	W11-W	187.90				187.90
W11-F	FS-Cu-2	179.700	180.300	176.500	178.900	2.040	1.140	FS-Cu-2	W11-F	178.90				178.90
W12-M	FS-Cu-2	107.400	114.200	110.700	110.800	3.390	3.060	FS-Cu-2	W12-M	110.80				110.80
W12-W	FS-Cu-2	105.800	102.000	105.400	104.400	2.070	1.980	FS-Cu-2	W12-W	104.40				104.40
W12-F	FS-Cu-2	57.230	55.080	59.140	57.150	2.030	3.550	FS-Cu-2	W12-F	57.15				57.15
W13-M	FS-Cu-2	172.700	167.100	165.900	168.600	3.650	2.170	FS-Cu-2	W13-M	168.60				168.60
W13-W	FS-Cu-2	93.780	100.200	100.400	98.120	3.756	3.830	FS-Cu-2	W13-W	98.12				98.12
W13-F	FS-Cu-2	99.790	99.400	102.200	100.500	1.540	1.530	FS-Cu-2	W13-F	100.50				100.50
W14-M	FS-Cu-2	146.000	139.500	139.200	141.600	3.820	2.700	FS-Cu-2	W14-M	141.60				141.60
W14-W	FS-Cu-2	188.000	184.600	186.000	186.200	1.720	0.920	FS-Cu-2	W14-W	186.20				186.20
W14-F	FS-Cu-2	173.400	163.800	165.900	167.700	5.060	3.020	FS-Cu-2	W14-F	167.70				167.70
W15-M	FS-Cu-2	173.400	163.800	165.900	1677.000	5.060	3.020	FS-Cu-2	W15-M	1677.00				1677.00
W15-W	FS-Cu-2	148.700	145.900	145.300	146.700	1.800	1.230	FS-Cu-2	W15-W	146.70				146.70
W15-F	FS-Cu-2	106.000	108.100	107.400	107.200	1.080	1.010	FS-Cu-2	W15-F	107.20				107.20
W16-M	FS-Cu-2	156.400	152.700	152.100	153.700	2.350	1.530	FS-Cu-2	W16-M	153.70				153.70
W16-W	FS-Cu-2	94.910	98.510	92.040	95.150	3.242	3.410	FS-Cu-2	W16-W	95.15				95.15
W16-F	FS-Cu-2	72.310	76.220	73.580	74.040	1.993	2.690	FS-Cu-2	W16-F	74.04				74.04
W17-M	FS-Cu-2	61.390	59.700	64.140	61.740	2.241	3.630	FS-Cu-2	W17-M	61.74				61.74
W17-W	FS-Cu-2	66.180	68.460	69.060	67.900	1.523	2.240	FS-Cu-2	W17-W	67.90				67.90
W17-F	FS-Cu-2	62.310	65.330	63.530	63.720	1.523	2.390	FS-Cu-2	W17-F	63.72				63.72
W18-M	FS-Cu-2	85.520	75.370	76.110	79.000	5.659	7.160	FS-Cu-2	W18-M	79.00				79.00
W18-W	FS-Cu-2	61.360	66.920	64.570	64.280	2.788	4.340	FS-Cu-2	W18-W	64.28				64.28
W18-F	FS-Cu-2	85.860	73.020	80.060	79.640	6.430	8.070	FS-Cu-2	W18-F	79.64				79.64
W19-M	FS-Cu-2	80.950	80.900	81.980	81.280	0.612	0.750	FS-Cu-2	W19-M	81.28				81.28
W19-W	FS-Cu-2	81.400	77.980	78.690	79.360	1.805	2.270	FS-Cu-2	W19-W	79.36				79.36
W19-F	FS-Cu-2	76.840	73.090	72.830	74.250	2.244	3.020	FS-Cu-2	W19-F	74.25				74.25
W20-M	FS-Cu-2	73.670	75.220	79.630	76.170	3.092	4.060	FS-Cu-2	W20-M	76.17				76.17
W20-W	FS-Cu-2	73.090	72.350	69.800	71.750	1.723	2.400	FS-Cu-2	W20-W	71.75				71.75
W20-F	FS-Cu-2	53.820	52.590	53.540	53.320	0.649	1.220	FS-Cu-2	W20-F	53.32				53.32
W21-M	FS-Cu-2	66.030	65.340	67.480	66.280	1.090	1.640	FS-Cu-2	W21-M	66.28				66.28
W21-W	FS-Cu-2	47.280	49.980	50.390	49.210	1.690	3.430	FS-Cu-2	W21-W	49.21				49.21
W21-F	FS-Cu-2	42.500	41.540	50.280	44.780	4.791	10.700	FS-Cu-2	W21-F	44.78				44.78
W22-M	FS-Cu-2	67.380	55.240	54.550	59.060	7.215	12.220	FS-Cu-2	W22-M	59.06				59.06
W22-W	FS-Cu-2	54.930	55.400	55.180	56.170	1.754	3.120	FS-Cu-2	W22-W	56.17				56.17
W22-F	FS-Cu-2	50.370	54.170	51.790	52.110	1.920	3.680	FS-Cu-2	W22-F	52.11				52.11
W23-M	FS-Cu-2	36.730	37.260	40.650	38.220	2.128	5.570	FS-Cu-2	W23-M	38.22				38.22
W23-W	FS-Cu-2	36.047	39.850	31.350	35.760	4.256	11.900	FS-Cu-2	W23-W	35.76				35.76
W23-F	FS-Cu-2	28.950	24.050	22.360	25.120	3.427	13.640	FS-Cu-2	W23-F	25.12				25.12
W24-M	FS-Cu-2	20.200	12.120	12.620	14.698	4.527	30.220	FS-Cu-2	W24-M	14.70				14.70
W24-W	FS-Cu-2	28.020	26.180	27.660	27.290	0.977	3.580	FS-Cu-2	W24-W	27.29				27.29
W24-F	FS-Cu-2	18.730	18.700	18.710	18.710	0.013	0.070	FS-Cu-2	W24-F	18.71				18.71
W25-M	FS-Cu-2	23.350	22.300	22.020	22.550	0.701	3.110	FS-Cu-2	W25-M	22.55				22.55
W25-W	FS-Cu-2	17.780	18.000	17.810	17.860	0.120	0.670	FS-Cu-2	W25-W	17.86				17.86
W25-F	FS-Cu-2	5.636	4.709	4.684	5.010	0.543	10.830	FS-Cu-2	W25-F	5.01				5.01
W26-M	FS-Cu-2	5.358	6.847	8.720	6.975	1.685	24.150	FS-Cu-2	W26-M	6.98				6.98
W26-W	FS-Cu-2	6.658	4.896	5.460	5.671	0.900	15.860	FS-Cu-2	W26-W	5.67				5.67
W26-F	FS-Cu-2	19.610	20.920	22.700	21.070	1.551	7.360	FS-Cu-2	W26-F	21.07				21.07
W27-M	FS-Cu-2	30.980	32.540	31.350	31.620	0.817	2.580	FS-Cu-2	W27-M	31.62				31.62

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Pb-1	4108.000	4411.000	4306.000	4275.000	153.700	3.590	FS-Pb-1	W1-W	4275.00	5243.50	W1	3517.75	4275.00
W1-F	FS-Pb-1	1919.000	1831.000	1852.000	1867.000	45.700	2.450	FS-Pb-1	W1-F	1867.00	1792.00	W2	2146.25	1867.00
W2-M	FS-Pb-1	2371.000	1934.000	2319.000	2208.000	239.000	10.820	FS-Pb-1	W2-M	2208.00	2599.50	W3	2139.08	2208.00
W2-W	FS-Pb-1-Comp	-	-	-	-	-	-	FS-Pb-1-Comp	W2-W			W4	1669.83	-
W2-F	FS-Pb-1	1096.000	2249.000	2412.000	1919.000	717.500	37.390	FS-Pb-1	W2-F	1919.00	1693.00	W5	1727.33	1919.00
W3-M	FS-Pb-1	1231.000	1680.000	1303.000	1405.000	241.000	17.150	FS-Pb-1	W3-M	1405.00	1608.50	W6	1853.00	1405.00
W3-W	FS-Pb-1	3944.000	3868.000	3937.000	3916.000	42.500	1.080	FS-Pb-1	W3-W	3916.00	3272.50	W7	1917.33	3916.00
W3-F	FS-Pb-1	1533.000	1762.000	1842.000	1712.000	160.200	9.360	FS-Pb-1	W3-F	1712.00	1536.25	W8	1854.50	1712.00
W4-M	FS-Pb-1	1923.000	1925.000	1696.000	1848.000	131.400	7.110	FS-Pb-1	W4-M	1848.00	1927.00	W9	1632.00	1848.00
W4-W	FS-Pb-1	1469.000	1510.000	1422.000	1467.000	43.800	2.990	FS-Pb-1	W4-W	1467.00	1625.50	W10	1482.17	1467.00
W4-F	FS-Pb-1	1522.000	1311.000	1368.000	1400.000	109.100	7.790	FS-Pb-1	W4-F	1400.00	1457.00	W11	5073.17	1400.00
W5-M	FS-Pb-1	1583.000	1616.000	1530.000	1576.000	43.900	2.780	FS-Pb-1	W5-M	1576.00	1640.00	W12	1196.23	1576.00
W5-W	FS-Pb-1	1729.000	1799.000	1812.000	1780.000	44.500	2.500	FS-Pb-1	W5-W	1780.00	1832.00	W13	1424.17	1780.00
W5-F	FS-Pb-1	1557.000	1589.000	1605.000	1584.000	24.200	1.530	FS-Pb-1	W5-F	1584.00	1710.00	W14	1472.33	1584.00
W6-M	FS-Pb-1	1602.000	1571.000	1607.000	1594.000	19.300	1.210	FS-Pb-1	W6-M	1594.00	1650.50	W15	1648.33	1594.00
W6-W	FS-Pb-1	1840.000	1956.000	1841.000	1879.000	66.400	3.530	FS-Pb-1	W6-W	1879.00	1929.00	W16	1898.83	1879.00
W6-F	FS-Pb-1	1914.000	1905.000	1924.000	1914.000	9.700	0.510	FS-Pb-1	W6-F	1914.00	1979.50	W17	1336.00	1914.00
W7-M	FS-Pb-1	1801.000	1810.000	1811.000	1807.000	5.700	0.310	FS-Pb-1	W7-M	1807.00	1872.50	W18	1094.80	1807.00
W7-W	FS-Pb-1	1871.000	1965.000	1908.000	1915.000	47.500	2.480	FS-Pb-1	W7-W	1915.00	1953.00	W19	983.83	1915.00
W7-F	FS-Pb-1	1837.000	1799.000	1848.000	1828.000	25.500	1.400	FS-Pb-1	W7-F	1828.00	1926.50	W20	1306.50	1828.00
W8-M	FS-Pb-1	1699.000	1744.000	1740.000	1728.000	25.100	1.450	FS-Pb-1	W8-M	1728.00	1858.00	W21	890.37	1728.00
W8-W	FS-Pb-1	1759.000	1857.000	1787.000	1801.000	50.800	2.820	FS-Pb-1	W8-W	1801.00	1870.00	W22	802.78	1801.00
W8-F	FS-Pb-1	1755.000	1666.000	1750.000	1723.000	49.900	2.900	FS-Pb-1	W8-F	1723.00	1835.50	W23	882.03	1723.00
W9-M	FS-Pb-1	1684.000	1702.000	1687.000	1691.000	9.500	0.560	FS-Pb-1	W9-M	1691.00	1775.00	W24	642.92	1691.00
W9-W	FS-Pb-1	1610.000	1621.000	1612.000	1614.000	5.700	0.350	FS-Pb-1	W9-W	1614.00	1598.50	W25	579.88	1614.00
W9-F	FS-Pb-1	1398.000	1372.000	1384.000	1385.000	12.800	0.920	FS-Pb-1	W9-F	1385.00	1522.50	W26	560.22	1385.00
W10-M	FS-Pb-1	1286.000	1314.000	1296.000	1299.000	14.000	1.080	FS-Pb-1	W10-M	1299.00	1471.00	W27	1173.00	1299.00
W10-W	FS-Pb-1	1184.000	1255.000	1242.000	1227.000	37.700	3.080	FS-Pb-1	W10-W	1227.00	1348.00			1227.00
W10-F	FS-Pb-1	1418.000	1459.000	1459.000	1445.000	23.400	1.620	FS-Pb-1	W10-F	1445.00	1627.50			1445.00
W11-M	FS-Pb-1	7635.000	8091.000	8580.000	8102.000	472.500	5.830	FS-Pb-1	W11-M	8102.00	7753.00			8102.00
W11-W	FS-Pb-1	5717.000	6122.000	5742.000	5860.000	227.100	3.870	FS-Pb-1	W11-W	5860.00	4031.00			5860.00
W11-F	FS-Pb-1	3461.000	3538.000	3524.000	3508.000	41.100	1.170	FS-Pb-1	W11-F	3508.00	3435.50			3508.00
W12-M	FS-Pb-1	1712.000	1718.000	1647.000	1692.000	39.400	2.330	FS-Pb-1	W12-M	1692.00	1717.50			1692.00
W12-W	FS-Pb-1	1270.000	1330.000	1303.000	1301.000	30.100	2.310	FS-Pb-1	W12-W	1301.00	1342.00			1301.00
W12-F	FS-Pb-1	578.200	548.800	539.300	555.400	20.280	3.650	FS-Pb-1	W12-F	555.40	529.20			555.40
W13-M	FS-Pb-1	1500.000	1594.000	1520.000	1538.000	49.500	3.220	FS-Pb-1	W13-M	1538.00	1528.50			1538.00
W13-W	FS-Pb-1	1404.000	1487.000	1394.000	1428.000	51.100	3.580	FS-Pb-1	W13-W	1428.00	1450.00			1428.00
W13-F	FS-Pb-1	1280.000	1227.000	1192.000	1233.000	44.200	3.580	FS-Pb-1	W13-F	1233.00	1294.00			1233.00
W14-M	FS-Pb-1	1213.000	1215.000	1249.000	1225.000	20.300	1.660	FS-Pb-1	W14-M	1225.00	1302.50			1225.00
W14-W	FS-Pb-1	1211.000	1191.000	1188.000	1197.000	12.500	1.050	FS-Pb-1	W14-W	1197.00	1287.50			1197.00
W14-F	FS-Pb-1	1671.000	1664.000	1671.000	1669.000	4.000	0.240	FS-Pb-1	W14-F	1669.00	1827.00			1669.00
W15-M	FS-Pb-1	1524.000	1533.000	1469.000	1508.000	34.900	2.310	FS-Pb-1	W15-M	1508.00	1760.50			1508.00
W15-W	FS-Pb-1	1450.000	1508.000	1471.000	1476.000	29.600	2.000	FS-Pb-1	W15-W	1476.00	1476.00			1476.00
W15-F	FS-Pb-1	1524.000	1588.000	1577.000	1563.000	33.900	2.170	FS-Pb-1	W15-F	1563.00	1708.50			1563.00
W16-M	FS-Pb-1	1614.000	1647.000	1556.000	1606.000	45.900	2.860	FS-Pb-1	W16-M	1606.00	1762.50			1606.00
W16-W	FS-Pb-1	1754.000	1958.000	1971.000	1984.000	122.100	6.440	FS-Pb-1	W16-W	1984.00	2471.00			1984.00
W16-F	FS-Pb-1	1355.000	1330.000	1335.000	1340.000	13.000	0.970	FS-Pb-1	W16-F	1340.00	1463.00			1340.00
W17-M	FS-Pb-1	1192.000	1201.000	1236.000	1210.000	23.300	1.930	FS-Pb-1	W17-M	1210.00	1324.50			1210.00
W17-W	FS-Pb-1	1233.000	1187.000	1289.000	1236.000	51.100	4.130	FS-Pb-1	W17-W	1236.00	1255.50			1236.00
W17-F	FS-Pb-1	1352.000	1343.000	1403.000	1366.000	32.700	2.390	FS-Pb-1	W17-F	1366.00	1428.00			1366.00
W18-M	FS-Pb-1	1264.000	1254.000	1213.000	1244.000	26.900	2.170	FS-Pb-1	W18-M	1244.00	1335.00			1244.00
W18-W	FS-Pb-1	998.500	1061.000	1099.000	1053.000	50.900	4.840	FS-Pb-1	W18-W	1053.00	1069.50			1053.00
W18-F	FS-Pb-1	858.700	788.700	816.400	821.300	35.250	4.290	FS-Pb-1	W18-F	821.30	879.90			821.30
W19-M	FS-Pb-1	825.500	900.200	875.200	867.000	38.020	4.390	FS-Pb-1	W19-M	867.00	959.50			867.00
W19-W	FS-Pb-1	900.800	876.300	886.900	888.000	12.290	1.380	FS-Pb-1	W19-W	888.00	919.50			888.00
W19-F	FS-Pb-1	1037.000	1064.000	1065.000	1055.000	15.700	1.490	FS-Pb-1	W19-F	1055.00	1072.50			1055.00
W20-M	FS-Pb-1	1367.000	1392.000	1385.000	1381.000	13.000	0.940	FS-Pb-1	W20-M	1381.00	1376.00			1381.00
W20-W	FS-Pb-1	1433.000	1413.000	1388.000	1411.000	22.600	1.600	FS-Pb-1	W20-W	1411.00	1361.50			1411.00
W20-F	FS-Pb-1	1153.000	1180.000	1144.000	1159.000	18.600	1.610	FS-Pb-1	W20-F	1159.00	1182.00			1159.00
W21-M	FS-Pb-1	1241.000	1231.000	1230.000	1234.000	6.100	0.490	FS-Pb-1	W21-M	1234.00	1249.00			1234.00
W21-W	FS-Pb-1	546.000	545.800	548.500	546.800	1.530	0.280	FS-Pb-1	W21-W	546.80	450.90			546.80
W21-F	FS-Pb-1	925.100	835.000	845.200	868.400	49.310	5.680	FS-Pb-1	W21-F	868.40	971.20			868.40
W22-M	FS-Pb-1	156.900	204.700	186.200	182.600	24.120	13.210	FS-Pb-1	W22-M	182.60	284.85			182.60
W22-W	FS-Pb-1	1125.000	1080.000	1085.000	1096.000	24.600	2.250	FS-Pb-1	W22-W	1096.00	1129.00			1096.00
W22-F	FS-Pb-1	838.900	871.800	875.400	862.000	20.130	2.340	FS-Pb-1	W22-F	862.00	994.50			862.00
W23-M	FS-Pb-1	886.500	883.300	818.300	862.700	38.500	4.460	FS-Pb-1	W23-M	862.70	953.85			862.70
W23-W	FS-Pb-1	812.600	849.700	878.600	847.000	33.070	3.900	FS-Pb-1	W23-W	847.00	943.00			847.00
W23-F	FS-Pb-1	687.500	677.200	663.600	676.100	11.950	1.770	FS-Pb-1	W23-F	676.10	749.25			676.10
W24-M	FS-Pb-1	585.600	579.900	499.100	554.900	48.360	8.720	FS-Pb-1	W24-M	554.90	598.05			554.90
W24-W	FS-Pb-1	486.000	597.100	621.700	568.300	72.300	12.720	FS-Pb-1	W24-W	568.30	663.55			568.30
W24-F	FS-Pb-1	564.100	568.000	547.800	559.900	10.710	1.910	FS-Pb-1	W24-F	559.90	667.15			559.90
W25-M	FS-Pb-1	536.900	548.800	549.300	545.000	7.000	1.280	FS-Pb-1	W25-M	545.00	657.15			545.00
W25-W	FS-Pb-1	755.700	762.400	705.900	741.300	30.900	4.170	FS-Pb-1	W25-W	741.30	651.25			741.30
W25-F	FS-Pb-1	368.100	364.800	263.400	332.100	59.520	17.920	FS-Pb-1	W25-F	332.10	431.25			332.10
W26-M	FS-Pb-1	388.600	398.200	409.200	398.700	10.300	2.580	FS-Pb-1	W26-M	398.70	469.20			398.70
W26-W	FS-Pb-1	417.300	427.200	397.200	413.900	15.330	3.700	FS-Pb-1	W26-W	413.90	440.95			413.90
W26-F	FS-Pb-1	753.100	609.700	781.300	714.700	92.030	12.880	FS-Pb-1	W26-F	714.70	770.50			714.70
W27-M	FS-Pb-1	1144.000	1133.000	1091.000	1122.000	28.000	2.490	FS-Pb-1	W27-M	1122.00	1173.00			1122.00

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Pb-2	5967.000	6304.000	6366.000	6212.000	214.500	3.450	FS-Pb-2	W1-W	6212.00				6212.00
W1-F	FS-Pb-2	1687.000	1722.000	1742.000	1717.000	27.500	1.600	FS-Pb-2	W1-F	1717.00				1717.00
W2-M	FS-Pb-2	2837.000	3069.000	3066.000	2991.000	133.200	4.450	FS-Pb-2	W2-M	2991.00				2991.00
W2-W	FS-Pb-2-Comp	-	-	-	-	-	-	FS-Pb-2-Comp	W2-W					-
W2-F	FS-Pb-2	1177.000	2162.000	1062.000	1467.000	604.300	41.190	FS-Pb-2	W2-F	1467.00				1467.00
W3-M	FS-Pb-2	2341.000	1463.000	1633.000	1812.000	465.600	25.690	FS-Pb-2	W3-M	1812.00				1812.00
W3-W	FS-Pb-2	2677.000	2654.000	2556.000	2629.000	64.200	2.440	FS-Pb-2	W3-W	2629.00				2629.00
W3-F	FS-Pb-2	1365.000	1356.000		1360.500	6.364		FS-Pb-2	W3-F	1360.50				1360.50
W4-M	FS-Pb-2	2075.000	1958.000	1986.000	2006.000	61.000	3.040	FS-Pb-2	W4-M	2006.00				2006.00
W4-W	FS-Pb-2	1906.000	1692.000	1754.000	1784.000	110.300	6.180	FS-Pb-2	W4-W	1784.00				1784.00
W4-F	FS-Pb-2	1494.000	1553.000	1495.000	1514.000	33.600	2.220	FS-Pb-2	W4-F	1514.00				1514.00
W5-M	FS-Pb-2	1646.000	1712.000	1754.000	1704.000	54.800	3.220	FS-Pb-2	W5-M	1704.00				1704.00
W5-W	FS-Pb-2	1895.000	1881.000	1876.000	1884.000	10.200	0.540	FS-Pb-2	W5-W	1884.00				1884.00
W5-F	FS-Pb-2	1847.000	1834.000	1826.000	1836.000	10.500	0.570	FS-Pb-2	W5-F	1836.00				1836.00
W6-M	FS-Pb-2	1744.000	1674.000	1703.000	1707.000	35.100	2.060	FS-Pb-2	W6-M	1707.00				1707.00
W6-W	FS-Pb-2	1921.000	2014.000	2004.000	1979.000	51.200	2.590	FS-Pb-2	W6-W	1979.00				1979.00
W6-F	FS-Pb-2	2050.000	2077.000	2009.000	2045.000	34.000	1.660	FS-Pb-2	W6-F	2045.00				2045.00
W7-M	FS-Pb-2	1977.000	1959.000	1877.000	1938.000	53.100	2.740	FS-Pb-2	W7-M	1938.00				1938.00
W7-W	FS-Pb-2	1987.000	1963.000	2024.000	1991.000	30.900	1.550	FS-Pb-2	W7-W	1991.00				1991.00
W7-F	FS-Pb-2	2040.000	2000.000	2036.000	2025.000	21.700	1.070	FS-Pb-2	W7-F	2025.00				2025.00
W8-M	FS-Pb-2	1955.000	1922.000	2087.000	1988.000	87.500	4.400	FS-Pb-2	W8-M	1988.00				1988.00
W8-W	FS-Pb-2	1971.000	1979.000	1866.000	1939.000	63.100	3.250	FS-Pb-2	W8-W	1939.00				1939.00
W8-F	FS-Pb-2	1981.000	1894.000	2020.000	1948.000	64.800	3.320	FS-Pb-2	W8-F	1948.00				1948.00
W9-M	FS-Pb-2	1812.000	1875.000	1889.000	1859.000	40.800	2.200	FS-Pb-2	W9-M	1859.00				1859.00
W9-W	FS-Pb-2	1644.000	1550.000	1556.000	1583.000	52.500	3.310	FS-Pb-2	W9-W	1583.00				1583.00
W9-F	FS-Pb-2	1737.000	1615.000	1629.000	1660.000	66.800	4.030	FS-Pb-2	W9-F	1660.00				1660.00
W10-M	FS-Pb-2	1662.000	1659.000	1610.000	1643.000	29.400	1.790	FS-Pb-2	W10-M	1643.00				1643.00
W10-W	FS-Pb-2	1464.000	1470.000	1474.000	1469.000	5.200	0.350	FS-Pb-2	W10-W	1469.00				1469.00
W10-F	FS-Pb-2	1848.000	1786.000	1795.000	1810.000	33.200	1.830	FS-Pb-2	W10-F	1810.00				1810.00
W11-M	FS-Pb-2	6769.000	7827.000	7615.000	7404.000	559.400	7.560	FS-Pb-2	W11-M	7404.00				7404.00
W11-W	FS-Pb-2	2167.000	2203.000	2237.000	2202.000	34.800	1.580	FS-Pb-2	W11-W	2202.00				2202.00
W11-F	FS-Pb-2	3372.000	3337.000	3381.000	3363.000	23.400	0.690	FS-Pb-2	W11-F	3363.00				3363.00
W12-M	FS-Pb-2	1728.000	1716.000	1784.000	1743.000	36.400	2.090	FS-Pb-2	W12-M	1743.00				1743.00
W12-W	FS-Pb-2	1379.000	1414.000	1357.000	1383.000	28.700	2.070	FS-Pb-2	W12-W	1383.00				1383.00
W12-F	FS-Pb-2	496.800	499.000	513.200	503.000	8.930	1.770	FS-Pb-2	W12-F	503.00				503.00
W13-M	FS-Pb-2	1523.000	1531.000	1504.000	1519.000	13.700	0.900	FS-Pb-2	W13-M	1519.00				1519.00
W13-W	FS-Pb-2	1485.000	1490.000	1442.000	1472.000	26.300	1.780	FS-Pb-2	W13-W	1472.00				1472.00
W13-F	FS-Pb-2	1322.000	1380.000	1362.000	1355.000	29.800	2.200	FS-Pb-2	W13-F	1355.00				1355.00
W14-M	FS-Pb-2	1383.000	1379.000	1379.000	1380.000	2.300	0.170	FS-Pb-2	W14-M	1380.00				1380.00
W14-W	FS-Pb-2	1367.000	1380.000	1387.000	1378.000	9.900	0.720	FS-Pb-2	W14-W	1378.00				1378.00
W14-F	FS-Pb-2	1977.000	1977.000	2001.000	1985.000	13.700	0.690	FS-Pb-2	W14-F	1985.00				1985.00
W15-M	FS-Pb-2	2028.000	2028.000	1983.000	2013.000	26.000	1.290	FS-Pb-2	W15-M	2013.00				2013.00
W15-W	FS-Pb-2	-	-	-	-	-	-	FS-Pb-2	W15-W					-
W15-F	FS-Pb-2	1877.000	1840.000	1846.000	1854.000	20.300	1.090	FS-Pb-2	W15-F	1854.00				1854.00
W16-M	FS-Pb-2	1921.000	1922.000	1915.000	1919.000	3.900	0.200	FS-Pb-2	W16-M	1919.00				1919.00
W16-W	FS-Pb-2	2935.000	3072.000	2867.000	2958.000	104.500	3.530	FS-Pb-2	W16-W	2958.00				2958.00
W16-F	FS-Pb-2	1565.000	1557.000	1637.000	1586.000	44.100	2.780	FS-Pb-2	W16-F	1586.00				1586.00
W17-M	FS-Pb-2	1437.000	1422.000	1459.000	1439.000	18.500	1.280	FS-Pb-2	W17-M	1439.00				1439.00
W17-W	FS-Pb-2	1197.000	1358.000	1270.000	1275.000	80.400	6.310	FS-Pb-2	W17-W	1275.00				1275.00
W17-F	FS-Pb-2	1581.000	1435.000	1453.000	1490.000	79.700	5.350	FS-Pb-2	W17-F	1490.00				1490.00
W18-M	FS-Pb-2	1387.000	1451.000	1440.000	1426.000	34.700	2.430	FS-Pb-2	W18-M	1426.00				1426.00
W18-W	FS-Pb-2	1115.000	1071.000	1072.000	1086.000	24.900	2.290	FS-Pb-2	W18-W	1086.00				1086.00
W18-F	FS-Pb-2	935.500	948.500	931.400	938.500	8.940	0.950	FS-Pb-2	W18-F	938.50				938.50
W19-M	FS-Pb-2	1041.000	1044.000	1070.000	1052.000	15.800	1.510	FS-Pb-2	W19-M	1052.00				1052.00
W19-W	FS-Pb-2	935.500	953.900	963.700	951.000	14.310	1.500	FS-Pb-2	W19-W	951.00				951.00
W19-F	FS-Pb-2	1126.000	1072.000	1073.000	1090.000	30.900	2.830	FS-Pb-2	W19-F	1090.00				1090.00
W20-M	FS-Pb-2	1375.000	1370.000	1368.000	1371.000	3.200	0.240	FS-Pb-2	W20-M	1371.00				1371.00
W20-W	FS-Pb-2	1298.000	1337.000	1300.000	1312.000	21.700	1.660	FS-Pb-2	W20-W	1312.00				1312.00
W20-F	FS-Pb-2	1207.000	1191.000	1216.000	1205.000	13.000	1.080	FS-Pb-2	W20-F	1205.00				1205.00
W21-M	FS-Pb-2	1246.000	1249.000	1297.000	1264.000	28.600	2.260	FS-Pb-2	W21-M	1264.00				1264.00
W21-W	FS-Pb-2	372.700	343.900	348.500	355.000	15.440	4.350	FS-Pb-2	W21-W	355.00				355.00
W21-F	FS-Pb-2	1047.000	1091.000	1084.000	1074.000	23.500	2.190	FS-Pb-2	W21-F	1074.00				1074.00
W22-M	FS-Pb-2	424.400	296.200	440.700	387.100	79.130	20.440	FS-Pb-2	W22-M	387.10				387.10
W22-W	FS-Pb-2	1162.000	1150.000	1174.000	1162.000	11.900	1.030	FS-Pb-2	W22-W	1162.00				1162.00
W22-F	FS-Pb-2	1134.000	1089.000	1158.000	1127.000	35.100	3.110	FS-Pb-2	W22-F	1127.00				1127.00
W23-M	FS-Pb-2	1053.000	1052.000	1030.000	1045.000	13.100	1.250	FS-Pb-2	W23-M	1045.00				1045.00
W23-W	FS-Pb-2	1018.000	1033.000	1066.000	1039.000	24.800	2.390	FS-Pb-2	W23-W	1039.00				1039.00
W23-F	FS-Pb-2	850.700	809.200	807.500	822.400	24.460	2.970	FS-Pb-2	W23-F	822.40				822.40
W24-M	FS-Pb-2	630.500	644.500	648.700	641.200	9.540	1.490	FS-Pb-2	W24-M	641.20				641.20
W24-W	FS-Pb-2	775.100	762.700	738.700	758.800	18.520	2.440	FS-Pb-2	W24-W	758.80				758.80
W24-F	FS-Pb-2	781.200	772.500	769.500	774.400	6.070	0.780	FS-Pb-2	W24-F	774.40				774.40
W25-M	FS-Pb-2	762.100	770.300	775.400	769.300	6.690	0.870	FS-Pb-2	W25-M	769.30				769.30
W25-W	FS-Pb-2	587.100	562.400	534.100	561.200	26.540	4.730	FS-Pb-2	W25-W	561.20				561.20
W25-F	FS-Pb-2	546.100	546.100	499.100	530.400	27.140	5.120	FS-Pb-2	W25-F	530.40				530.40
W26-M	FS-Pb-2	544.900	540.200	533.900	539.700	5.560	1.030	FS-Pb-2	W26-M	539.70				539.70
W26-W	FS-Pb-2	448.700	416.700	538.400	468.000	63.090	13.480	FS-Pb-2	W26-W	468.00				468.00
W26-F	FS-Pb-2	844.200	863.400	771.200	826.300	48.630	5.890	FS-Pb-2	W26-F	826.30				826.30
W27-M	FS-Pb-2	1125.000	1260.000	1288.000	1224.000	87.500	7.150	FS-Pb-2	W27-M	1224.00				1224.00

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Cu-1	3135.000	3280.000	3219.000	3211.000	72.900	2.270	PACl-Cu-1	W1-W	3211.00	3087.00	W1	2719.50	3211.00
W1-F	PACl-Cu-1	1919.000	1931.000	1983.000	1944.000	34.100	1.750	PACl-Cu-1	W1-F	1944.00	2352.00	W2	2202.17	1944.00
W2-M	PACl-Cu-1	1960.000	1877.000	1752.000	1863.000	104.800	5.620	PACl-Cu-1	W2-M	1863.00	2445.50	W3	1807.65	1863.00
W2-W	PACl-Cu-1	1768.000	1797.000	1788.000	1784.000	15.000	0.840	PACl-Cu-1	W2-W	1784.00	2306.50	W4	708.82	1784.00
W2-F	PACl-Cu-1	1878.000	1189.000	1326.000	1464.000	364.500	24.890	PACl-Cu-1	W2-F	1464.00	1854.50	W5	378.43	1464.00
W3-M	PACl-Cu-1	1677.000	1708.000	1758.000	1714.000	40.900	2.390	PACl-Cu-1	W3-M	1714.00	2547.00	W6	233.47	1714.00
W3-W	PACl-Cu-1	583.600	519.200	526.700	543.100	35.220	6.490	PACl-Cu-1	W3-W	543.10	1609.55	W7	155.15	543.10
W3-F	PACl-Cu-1	632.900	565.000	448.400	548.800	93.340	17.100	PACl-Cu-1	W3-F	548.80	1266.40	W8	128.66	548.80
W4-M	PACl-Cu-1	673.900	622.900	638.600	645.200	26.100	4.050	PACl-Cu-1	W4-M	645.20	1090.10	W9	103.90	645.20
W4-W	PACl-Cu-1	291.700	267.300	257.700	272.200	17.550	6.450	PACl-Cu-1	W4-W	272.20	549.30	W10	124.58	272.20
W4-F	PACl-Cu-1	234.500	301.600	283.800	273.300	34.740	12.710	PACl-Cu-1	W4-F	273.30	487.05	W11	95.12	273.30
W5-M	PACl-Cu-1	162.000	147.500	154.700	154.700	7.260	4.690	PACl-Cu-1	W5-M	154.70	360.40	W12	141.01	154.70
W5-W	PACl-Cu-1	227.800	213.400	196.300	212.500	15.780	7.430	PACl-Cu-1	W5-W	212.50	427.55	W13	77.95	212.50
W5-F	PACl-Cu-1	183.700	229.300	164.600	192.500	33.250	17.270	PACl-Cu-1	W5-F	192.50	347.35	W14	51.55	192.50
W6-M	PACl-Cu-1	142.700	127.400	104.100	124.700	19.440	15.590	PACl-Cu-1	W6-M	124.70	276.85	W15	54.20	124.70
W6-W	PACl-Cu-1	211.000	185.500	190.700	195.700	13.490	6.890	PACl-Cu-1	W6-W	195.70	191.65	W16	51.08	195.70
W6-F	PACl-Cu-1	157.500	127.700	127.000	137.400	17.390	12.660	PACl-Cu-1	W6-F	137.40	231.90	W17	33.82	137.40
W7-M	PACl-Cu-1	185.800	147.500	151.000	161.400	21.160	13.110	PACl-Cu-1	W7-M	161.40	265.30	W18	33.78	161.40
W7-W	PACl-Cu-1	59.260	32.510	35.940	42.570	14.554	34.190	PACl-Cu-1	W7-W	42.57	131.99	W19	65.83	42.57
W7-F	PACl-Cu-1	25.150	26.700	48.810	33.550	13.234	39.440	PACl-Cu-1	W7-F	33.55	68.18	W20	46.47	33.55
W8-M	PACl-Cu-1	75.020	82.790	75.680	77.830	4.311	5.540	PACl-Cu-1	W8-M	77.83	121.42	W21	46.95	77.83
W8-W	PACl-Cu-1	81.050	80.340	79.470	80.290	0.792	0.990	PACl-Cu-1	W8-W	80.29	147.95	W22	37.28	80.29
W8-F	PACl-Cu-1	76.990	80.080	79.680	78.920	1.683	2.130	PACl-Cu-1	W8-F	78.92	116.61	W23	29.84	78.92
W9-M	PACl-Cu-1	74.050	77.200	75.780	75.670	1.579	2.090	PACl-Cu-1	W9-M	75.67	120.64	W24	34.79	75.67
W9-W	PACl-Cu-1	89.640	86.270	75.700	83.870	7.275	8.670	PACl-Cu-1	W9-W	83.87	111.94	W25	24.28	83.87
W9-F	PACl-Cu-1	64.090	65.040	69.030	66.050	2.622	3.970	PACl-Cu-1	W9-F	66.05	79.13	W26	17.71	66.05
W10-M	PACl-Cu-1	65.590	64.570	65.650	65.270	0.609	0.930	PACl-Cu-1	W10-M	65.27	82.09	W27	20.50	65.27
W10-W	PACl-Cu-1	100.700	113.000	99.500	104.400	7.480	7.170	PACl-Cu-1	W10-W	104.40	135.50			104.40
W10-F	PACl-Cu-1	144.000	160.500	152.800	152.500	8.270	5.420	PACl-Cu-1	W10-F	152.50	156.15			152.50
W11-M	PACl-Cu-1	95.020	93.010	96.910	94.980	1.951	2.050	PACl-Cu-1	W11-M	94.98	121.04			94.98
W11-W	PACl-Cu-1	79.330	88.020	87.090	84.810	4.771	5.830	PACl-Cu-1	W11-W	84.81	89.62			84.81
W11-F	PACl-Cu-1	61.380	59.030	75.360	65.260	8.830	13.530	PACl-Cu-1	W11-F	65.26	74.71			65.26
W12-M	PACl-Cu-1	75.960	75.540	72.910	74.810	1.651	2.210	PACl-Cu-1	W12-M	74.81	88.86			74.81
W12-W	PACl-Cu-1	55.500	56.680	52.890	55.020	1.941	3.530	PACl-Cu-1	W12-W	55.02	76.72			55.02
W12-F	PACl-Cu-1	192.800	200.200	203.800	199.000	5.580	2.810	PACl-Cu-1	W12-F	199.00	257.45			199.00
W13-M	PACl-Cu-1	55.720	56.950	57.710	56.790	1.004	1.770	PACl-Cu-1	W13-M	56.79	112.45			56.79
W13-W	PACl-Cu-1	41.060	41.180	42.900	41.710	1.033	2.480	PACl-Cu-1	W13-W	41.71	55.29			41.71
W13-F	PACl-Cu-1	33.080	36.300	37.180	35.520	2.155	6.070	PACl-Cu-1	W13-F	35.52	66.11			35.52
W14-M	PACl-Cu-1	21.510	20.940	22.110	21.520	0.585	2.720	PACl-Cu-1	W14-M	21.52	49.52			21.52
W14-W	PACl-Cu-1	26.650	27.490	26.440	26.860	0.555	2.070	PACl-Cu-1	W14-W	26.86	48.56			26.86
W14-F	PACl-Cu-1	34.030	32.870	33.710	33.540	0.598	1.780	PACl-Cu-1	W14-F	33.54	56.57			33.54
W15-M	PACl-Cu-1	40.420	40.800	41.000	40.740	0.295	0.720	PACl-Cu-1	W15-M	40.74	59.76			40.74
W15-W	PACl-Cu-1	35.120	36.170	36.830	36.040	0.862	2.390	PACl-Cu-1	W15-W	36.04	54.84			36.04
W15-F	PACl-Cu-1	38.880	40.910	39.540	39.780	1.036	2.600	PACl-Cu-1	W15-F	39.78	48.00			39.78
W16-M	PACl-Cu-1	45.070	46.740	47.350	46.390	1.182	2.550	PACl-Cu-1	W16-M	46.39	60.45			46.39
W16-W	PACl-Cu-1	37.220	41.150	29.750	36.040	5.794	16.080	PACl-Cu-1	W16-W	36.04	43.70			36.04
W16-F	PACl-Cu-1	52.510	56.820	51.000	53.440	3.020	5.650	PACl-Cu-1	W16-F	53.44	49.11			53.44
W17-M	PACl-Cu-1	51.280	49.790	43.140	48.070	4.335	9.020	PACl-Cu-1	W17-M	48.07	47.07			48.07
W17-W	PACl-Cu-1	26.720	24.210	25.760	25.560	1.268	4.960	PACl-Cu-1	W17-W	25.56	22.05			25.56
W17-F	PACl-Cu-1	46.560	46.720	45.190	46.160	0.837	1.810	PACl-Cu-1	W17-F	46.16	32.34			46.16
W18-M	PACl-Cu-1	51.210	45.280	37.830	44.770	6.705	14.970	PACl-Cu-1	W18-M	44.77	39.36			44.77
W18-W	PACl-Cu-1	31.270	31.930	30.840	31.350	0.547	1.740	PACl-Cu-1	W18-W	31.35	29.27			31.35
W18-F	PACl-Cu-1	37.160	39.760	34.560	37.160	2.599	6.990	PACl-Cu-1	W18-F	37.16	32.71			37.16
W19-M	PACl-Cu-1	207.100	206.400	208.500	207.300	1.070	0.520	PACl-Cu-1	W19-M	207.30	117.40			207.30
W19-W	PACl-Cu-1	54.380	52.770	52.320	53.160	1.083	2.040	PACl-Cu-1	W19-W	53.16	43.26			53.16
W19-F	PACl-Cu-1	50.100	51.810	50.800	50.910	0.857	1.680	PACl-Cu-1	W19-F	50.91	36.82			50.91
W20-M	PACl-Cu-1	66.130	66.240	65.570	65.980	0.359	0.540	PACl-Cu-1	W20-M	65.98	47.78			65.98
W20-W	PACl-Cu-1	61.440	59.690	59.980	60.370	0.939	1.550	PACl-Cu-1	W20-W	60.37	44.94			60.37
W20-F	PACl-Cu-1	60.730	62.920	58.820	60.820	2.052	3.370	PACl-Cu-1	W20-F	60.82	46.70			60.82
W21-M	PACl-Cu-1	81.950	81.580	80.360	81.300	0.833	1.020	PACl-Cu-1	W21-M	81.30	67.12			81.30
W21-W	PACl-Cu-1	18.880	16.990	16.310	17.390	1.330	7.650	PACl-Cu-1	W21-W	17.39	41.17			17.39
W21-F	PACl-Cu-1	42.250	43.350	41.880	42.490	0.766	1.800	PACl-Cu-1	W21-F	42.49	32.56			42.49
W22-M	PACl-Cu-1	49.710	48.460	48.620	48.930	0.683	1.400	PACl-Cu-1	W22-M	48.93	39.93			48.93
W22-W	PACl-Cu-1	25.040	23.720	30.790	26.510	3.761	14.180	PACl-Cu-1	W22-W	26.51	28.53			26.51
W22-F	PACl-Cu-1	49.500	52.700	51.190	51.130	1.601	3.130	PACl-Cu-1	W22-F	51.13	43.40			51.13
W23-M	PACl-Cu-1	41.020	39.130	39.490	39.880	1.007	2.530	PACl-Cu-1	W23-M	39.88	34.12			39.88
W23-W	PACl-Cu-1	31.890	31.550	31.880	31.770	0.191	0.600	PACl-Cu-1	W23-W	31.77	27.28			31.77
W23-F	PACl-Cu-1	18.530	23.000	19.350	20.300	2.381	11.730	PACl-Cu-1	W23-F	20.30	28.11			20.30
W24-M	PACl-Cu-1	52.880	50.830	50.110	51.270	1.439	2.810	PACl-Cu-1	W24-M	51.27	38.43			51.27
W24-W	PACl-Cu-1	48.440	50.630	48.690	49.250	1.197	2.430	PACl-Cu-1	W24-W	49.25	36.92			49.25
W24-F	PACl-Cu-1	42.600	42.350	42.060	42.340	0.272	0.640	PACl-Cu-1	W24-F	42.34	29.02			42.34
W25-M	PACl-Cu-1	24.880	23.770	23.010	23.890	0.936	3.920	PACl-Cu-1	W25-M	23.89	33.48			23.89
W25-W	PACl-Cu-1	38.170	38.260	37.290	37.910	0.539	1.420	PACl-Cu-1	W25-W	37.91	25.11			37.91
W25-F	PACl-Cu-1	21.990	21.210	22.220	21.810	0.528	2.420	PACl-Cu-1	W25-F	21.81	14.25			21.81
W26-M	PACl-Cu-1	19.150	20.390	20.440	19.990	0.730	3.650	PACl-Cu-1	W26-M	19.99	12.67			19.99
W26-W	PACl-Cu-1	15.240	15.160	18.480	16.290	1.891	11.600	PACl-Cu-1	W26-W	16.29	13.04			16.29
W26-F	PACl-Cu-1	27.760	27.950	28.090	27.940	0.166	0.590	PACl-Cu-1	W26-F	27.94	27.42			27.94
W27-M	PACl-Cu-1	20.620	21.140	19.740	20.500	0.706	3.440	PACl-Cu-1	W27-M	20.50	20.50			20.50

		Pb (Total)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Cu-2	3002.000	2966.000	2922.000	2963.000	39.700	1.340	PACl-Cu-2	W1-W	2963.00				2963.00
W1-F	PACl-Cu-2	28.420	2676.000	2761.000	2760.000	83.100	3.010	PACl-Cu-2	W1-F	2760.00				2760.00
W2-M	PACl-Cu-2	3179.000	2956.000	2949.000	3028.000	130.600	4.310	PACl-Cu-2	W2-M	3028.00				3028.00
W2-W	PACl-Cu-2	2808.000	2887.000	2792.000	2829.000	50.800	1.800	PACl-Cu-2	W2-W	2829.00				2829.00
W2-F	PACl-Cu-2	2203.000	2389.000	2141.000	2245.000	129.200	5.760	PACl-Cu-2	W2-F	2245.00				2245.00
W3-M	PACl-Cu-2	3148.000	3476.000	3517.000	3380.000	202.300	5.990	PACl-Cu-2	W3-M	3380.00				3380.00
W3-W	PACl-Cu-2	2721.000	2637.000	2670.000	2676.000	42.000	1.570	PACl-Cu-2	W3-W	2676.00				2676.00
W3-F	PACl-Cu-2	1914.000	2074.000	1964.000	1984.000	81.960	4.130	PACl-Cu-2	W3-F	1984.00				1984.00
W4-M	PACl-Cu-2	1569.000	1563.000	1472.000	1535.000	54.500	3.550	PACl-Cu-2	W4-M	1535.00				1535.00
W4-W	PACl-Cu-2	791.600	899.900	787.700	826.400	63.660	7.700	PACl-Cu-2	W4-W	826.40				826.40
W4-F	PACl-Cu-2	712.300	676.000	714.100	700.800	21.500	3.070	PACl-Cu-2	W4-F	700.80				700.80
W5-M	PACl-Cu-2	551.800	579.300	567.000	566.100	13.760	2.430	PACl-Cu-2	W5-M	566.10				566.10
W5-W	PACl-Cu-2	629.300	645.400	653.200	642.600	12.210	1.900	PACl-Cu-2	W5-W	642.60				642.60
W5-F	PACl-Cu-2	492.900	511.300	502.300	502.200	9.190	1.830	PACl-Cu-2	W5-F	502.20				502.20
W6-M	PACl-Cu-2	422.700	428.700	435.400	429.000	6.340	1.480	PACl-Cu-2	W6-M	429.00				429.00
W6-W	PACl-Cu-2	188.400	178.200	196.000	187.600	8.920	4.750	PACl-Cu-2	W6-W	187.60				187.60
W6-F	PACl-Cu-2	321.100	324.200	333.800	326.400	6.640	2.040	PACl-Cu-2	W6-F	326.40				326.40
W7-M	PACl-Cu-2	370.900	368.200	368.600	369.200	1.430	0.390	PACl-Cu-2	W7-M	369.20				369.20
W7-W	PACl-Cu-2	278.600	200.000	185.800	221.400	50.010	22.580	PACl-Cu-2	W7-W	221.40				221.40
W7-F	PACl-Cu-2	88.180	132.500	87.640	102.800	25.720	25.030	PACl-Cu-2	W7-F	102.80				102.80
W8-M	PACl-Cu-2	165.200	164.400	165.400	165.000	0.560	0.340	PACl-Cu-2	W8-M	165.00				165.00
W8-W	PACl-Cu-2	216.100	214.000	216.700	215.600	1.420	0.660	PACl-Cu-2	W8-W	215.60				215.60
W8-F	PACl-Cu-2	148.600	169.100	145.300	154.300	12.920	8.370	PACl-Cu-2	W8-F	154.30				154.30
W9-M	PACl-Cu-2	163.500	163.200	169.900	165.600	3.800	2.290	PACl-Cu-2	W9-M	165.60				165.60
W9-W	PACl-Cu-2	146.800	137.900	135.900	140.000	6.070	4.330	PACl-Cu-2	W9-W	140.00				140.00
W9-F	PACl-Cu-2	92.290	92.270	92.070	92.210	0.119	0.130	PACl-Cu-2	W9-F	92.21				92.21
W10-M	PACl-Cu-2	97.560	99.960	99.180	98.900	1.224	1.240	PACl-Cu-2	W10-M	98.90				98.90
W10-W	PACl-Cu-2	186.100	162.900	150.900	166.600	17.900	10.740	PACl-Cu-2	W10-W	166.60				166.60
W10-F	PACl-Cu-2	157.200	161.200	161.100	159.800	2.290	1.430	PACl-Cu-2	W10-F	159.80				159.80
W11-M	PACl-Cu-2	147.600	140.100	153.700	147.100	6.840	4.650	PACl-Cu-2	W11-M	147.10				147.10
W11-W	PACl-Cu-2	96.610	91.230	95.420	94.420	2.827	2.990	PACl-Cu-2	W11-W	94.42				94.42
W11-F	PACl-Cu-2	82.490	93.030	76.960	84.160	8.165	9.700	PACl-Cu-2	W11-F	84.16				84.16
W12-M	PACl-Cu-2	101.700	102.200	104.800	102.900	1.690	1.650	PACl-Cu-2	W12-M	102.90				102.90
W12-W	PACl-Cu-2	96.650	97.270	101.300	98.410	2.533	2.570	PACl-Cu-2	W12-W	98.41				98.41
W12-F	PACl-Cu-2	310.800	319.200	317.700	315.900	4.490	1.420	PACl-Cu-2	W12-F	315.90				315.90
W13-M	PACl-Cu-2	171.100	168.000	165.300	168.100	2.910	1.730	PACl-Cu-2	W13-M	168.10				168.10
W13-W	PACl-Cu-2	68.110	69.030	69.480	68.870	0.695	1.010	PACl-Cu-2	W13-W	68.87				68.87
W13-F	PACl-Cu-2	96.720	97.370	95.970	96.690	0.698	0.720	PACl-Cu-2	W13-F	96.69				96.69
W14-M	PACl-Cu-2	76.910	76.050	79.610	77.520	1.857	2.400	PACl-Cu-2	W14-M	77.52				77.52
W14-W	PACl-Cu-2	70.790	69.490	70.500	70.260	0.683	0.970	PACl-Cu-2	W14-W	70.26				70.26
W14-F	PACl-Cu-2	81.120	78.760	78.930	79.600	1.320	1.660	PACl-Cu-2	W14-F	79.60				79.60
W15-M	PACl-Cu-2	78.420	82.090	75.840	78.780	3.142	3.990	PACl-Cu-2	W15-M	78.78				78.78
W15-W	PACl-Cu-2	73.850	73.190	73.860	73.630	0.383	0.520	PACl-Cu-2	W15-W	73.63				73.63
W15-F	PACl-Cu-2	60.940	47.720	59.970	56.210	7.370	13.110	PACl-Cu-2	W15-F	56.21				56.21
W16-M	PACl-Cu-2	74.860	75.400	73.260	74.500	1.113	1.490	PACl-Cu-2	W16-M	74.50				74.50
W16-W	PACl-Cu-2	44.510	50.500	59.020	51.350	7.293	14.200	PACl-Cu-2	W16-W	51.35				51.35
W16-F	PACl-Cu-2	48.330	44.400	41.580	44.770	3.392	7.580	PACl-Cu-2	W16-F	44.77				44.77
W17-M	PACl-Cu-2	37.200	51.170	49.810	46.060	7.700	16.720	PACl-Cu-2	W17-M	46.06				46.06
W17-W	PACl-Cu-2	18.190	18.450	18.940	18.530	0.383	2.070	PACl-Cu-2	W17-W	18.53				18.53
W17-F	PACl-Cu-2	18.630	18.480	18.430	18.520	0.106	0.570	PACl-Cu-2	W17-F	18.52				18.52
W18-M	PACl-Cu-2	32.670	26.640	42.510	33.940	8.010	23.600	PACl-Cu-2	W18-M	33.94				33.94
W18-W	PACl-Cu-2	27.470	26.590	27.510	27.190	0.522	1.920	PACl-Cu-2	W18-W	27.19				27.19
W18-F	PACl-Cu-2	28.600	26.490	29.670	28.250	1.614	5.710	PACl-Cu-2	W18-F	28.25				28.25
W19-M	PACl-Cu-2	23.960	28.300	30.210	27.490	3.203	11.650	PACl-Cu-2	W19-M	27.49				27.49
W19-W	PACl-Cu-2	33.910	32.580	33.600	33.360	0.696	2.090	PACl-Cu-2	W19-W	33.36				33.36
W19-F	PACl-Cu-2	24.570	22.670	20.950	22.730	1.808	7.950	PACl-Cu-2	W19-F	22.73				22.73
W20-M	PACl-Cu-2	27.840	30.630	30.260	29.580	1.517	5.130	PACl-Cu-2	W20-M	29.58				29.58
W20-W	PACl-Cu-2	30.900	26.910	30.740	29.510	2.257	7.650	PACl-Cu-2	W20-W	29.51				29.51
W20-F	PACl-Cu-2	32.730	32.640	32.370	32.580	0.184	0.560	PACl-Cu-2	W20-F	32.58				32.58
W21-M	PACl-Cu-2	52.780	52.770	53.270	52.940	0.285	0.540	PACl-Cu-2	W21-M	52.94				52.94
W21-W	PACl-Cu-2	65.810	65.500	63.510	64.940	1.252	1.930	PACl-Cu-2	W21-W	64.94				64.94
W21-F	PACl-Cu-2	22.220	22.780	22.870	22.620	0.351	1.550	PACl-Cu-2	W21-F	22.62				22.62
W22-M	PACl-Cu-2	33.600	30.450	28.740	30.930	2.463	7.960	PACl-Cu-2	W22-M	30.93				30.93
W22-W	PACl-Cu-2	31.740	29.150	30.740	30.540	1.307	4.280	PACl-Cu-2	W22-W	30.54				30.54
W22-F	PACl-Cu-2	35.530	35.650	35.790	35.660	0.133	0.370	PACl-Cu-2	W22-F	35.66				35.66
W23-M	PACl-Cu-2	26.420	32.410	26.220	28.350	3.517	12.410	PACl-Cu-2	W23-M	28.35				28.35
W23-W	PACl-Cu-2	21.720	22.010	24.630	22.790	1.601	7.030	PACl-Cu-2	W23-W	22.79				22.79
W23-F	PACl-Cu-2	37.770	35.830	34.160	35.920	1.810	5.040	PACl-Cu-2	W23-F	35.92				35.92
W24-M	PACl-Cu-2	26.890	27.080	22.770	25.580	2.433	9.510	PACl-Cu-2	W24-M	25.58				25.58
W24-W	PACl-Cu-2	20.430	20.260	33.070	24.580	7.346	29.880	PACl-Cu-2	W24-W	24.58				24.58
W24-F	PACl-Cu-2	18.750	15.150	13.160	15.690	2.830	18.040	PACl-Cu-2	W24-F	15.69				15.69
W25-M	PACl-Cu-2	48.660	37.780	42.770	43.070	5.449	12.650	PACl-Cu-2	W25-M	43.07				43.07
W25-W	PACl-Cu-2	16.090	10.630	10.190	12.310	3.287	26.710	PACl-Cu-2	W25-W	12.31				12.31
W25-F	PACl-Cu-2	8.122	7.292	4.640	6.684	1.819	27.210	PACl-Cu-2	W25-F	6.68				6.68
W26-M	PACl-Cu-2	5.740	5.154	5.130	5.342	0.346	6.470	PACl-Cu-2	W26-M	5.34				5.34
W26-W	PACl-Cu-2	11.390	10.890	7.093	9.792	2.350	24.000	PACl-Cu-2	W26-W	9.79				9.79
W26-F	PACl-Cu-2	27.870	26.050	26.750	26.890	0.917	3.410	PACl-Cu-2	W26-F	26.89				26.89
W27-M	PACl-Cu-2	-	-	-	-	-	-	PACl-Cu-2	W27-M					-

Week ID	Sample ID	Pb (Total) 1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Pb-1	2703.000	2600.000	2764.000	2689.000	82.700	3.080	PACl-Pb-1	W1-W	2689.00	8984.50	W1	6583.50	2689.00
W1-F	PACl-Pb-1	2012.000	2095.000	2006.000	2038.000	49.700	2.440	PACl-Pb-1	W1-F	2038.00	4182.50	W2	2009.20	2038.00
W2-M	PACl-Pb-1	3637.000	3484.000	3550.000	3557.000	76.400	2.150	PACl-Pb-1	W2-M	3557.00	3327.00	W3	6402.65	3557.00
W2-W	PACl-Pb-1	1555.000	1433.000	1398.000	1462.000	82.400	5.640	PACl-Pb-1	W2-W	1462.00	1422.50	W4	1789.02	1462.00
W2-F	PACl-Pb-1	1802.000	1492.000	1836.000	1710.000	189.800	11.100	PACl-Pb-1	W2-F	1710.00	1278.10	W5	1294.10	1710.00
W3-M	PACl-Pb-1	14610.000	16070.000	15980.000	15550.000	819.200	5.270	PACl-Pb-1	W3-M	15550.00	9951.50	W6	1201.33	15550.00
W3-W	PACl-Pb-1	11550.000	11370.000	11160.000	11360.000	196.900	1.730	PACl-Pb-1	W3-W	11360.00	6658.00	W7	953.43	11360.00
W3-F	PACl-Pb-1	5513.000	4688.000	456.000	4922.000	516.300	10.490	PACl-Pb-1	W3-F	4922.00	2598.45	W8	801.35	4922.00
W4-M	PACl-Pb-1	6555.000	5959.000	6561.000	6358.000	345.700	5.440	PACl-Pb-1	W4-M	6358.00	3573.55	W9	375.92	6358.00
W4-W	PACl-Pb-1	1067.000	1148.000	1071.000	1095.000	45.900	4.190	PACl-Pb-1	W4-W	1095.00	673.65	W10	815.15	1095.00
W4-F	PACl-Pb-1	1895.000	1981.000	1930.000	1935.000	43.100	2.230	PACl-Pb-1	W4-F	1935.00	1119.85	W11	8738.50	1935.00
W5-M	PACl-Pb-1	3587.000	3719.000	3796.000	3701.000	105.900	2.860	PACl-Pb-1	W5-M	3701.00	2380.50	W12	1529.17	3701.00
W5-W	PACl-Pb-1	1029.000	973.100	1067.000	1023.000	47.300	4.620	PACl-Pb-1	W5-W	1023.00	799.90	W13	1490.32	1023.00
W5-F	PACl-Pb-1	1062.000	1167.000	1137.000	1122.000	53.800	4.800	PACl-Pb-1	W5-F	1122.00	701.90	W14	712.72	1122.00
W6-M	PACl-Pb-1	1396.000	1414.000	1392.000	1400.000	11.900	0.850	PACl-Pb-1	W6-M	1400.00	982.85	W15	1173.50	1400.00
W6-W	PACl-Pb-1	1498.000	1534.000	1503.000	1512.000	19.700	1.300	PACl-Pb-1	W6-W	1512.00	1291.00	W16	1006.32	1512.00
W6-F	PACl-Pb-1	1944.000	1923.000	1982.000	1950.000	29.800	1.530	PACl-Pb-1	W6-F	1950.00	1330.15	W17	1050.12	1950.00
W7-M	PACl-Pb-1	1100.000	1120.000	1126.000	1115.000	13.600	1.220	PACl-Pb-1	W7-M	1115.00	791.15	W18	512.17	1115.00
W7-W	PACl-Pb-1	1703.000	1722.000	1711.000	1712.000	9.400	0.550	PACl-Pb-1	W7-W	1712.00	1272.80	W19	285.07	1712.00
W7-F	PACl-Pb-1	1283.000	1178.000	1266.000	1242.000	56.600	4.560	PACl-Pb-1	W7-F	1242.00	796.35	W20	557.38	1242.00
W8-M	PACl-Pb-1	475.600	476.000	507.600	486.400	18.350	3.770	PACl-Pb-1	W8-M	486.40	623.95	W21	853.30	486.40
W8-W	PACl-Pb-1	929.200	755.800	923.700	869.600	98.540	11.330	PACl-Pb-1	W8-W	869.60	700.60	W22	366.23	869.60
W8-F	PACl-Pb-1	1020.000	988.400	1027.000	1012.000	20.700	2.040	PACl-Pb-1	W8-F	1012.00	1079.50	W23	399.72	1012.00
W9-M	PACl-Pb-1	400.500	385.200	442.500	409.400	29.680	7.250	PACl-Pb-1	W9-M	409.40	487.15	W24	355.10	409.40
W9-W	PACl-Pb-1	431.700	454.400	440.800	442.300	11.440	2.590	PACl-Pb-1	W9-W	442.30	358.10	W25	213.67	442.30
W9-F	PACl-Pb-1	236.300	271.200	278.100	261.600	22.400	8.550	PACl-Pb-1	W9-F	261.60	282.50	W26	299.70	261.60
W10-M	PACl-Pb-1	222.700	174.200	171.200	189.400	28.900	15.260	PACl-Pb-1	W10-M	189.40	138.31	W27	359.20	189.40
W10-W	PACl-Pb-1	620.600	538.200	621.400	593.400	47.790	8.050	PACl-Pb-1	W10-W	593.40	369.15			593.40
W10-F	PACl-Pb-1	3150.000	3134.000	3008.000	3097.000	78.000	2.520	PACl-Pb-1	W10-F	3097.00	1938.00			3097.00
W11-M	PACl-Pb-1							PACl-Pb-1	W11-M		18210.00			
W11-W	PACl-Pb-1	3645.000	3693.000	3528.000	3622.000	85.000	2.350	PACl-Pb-1	W11-W	3622.00	3914.00			3622.00
W11-F	PACl-Pb-1	1515.000	1508.000	1579.000	1534.000	38.900	2.540	PACl-Pb-1	W11-F	1534.00	4091.50			1534.00
W12-M	PACl-Pb-1	1082.000	1069.000	1087.000	1079.000	8.900	0.830	PACl-Pb-1	W12-M	1079.00	1415.00			1079.00
W12-W	PACl-Pb-1	1117.000	1055.000	1023.000	1065.000	47.700	4.480	PACl-Pb-1	W12-W	1065.00	1428.50			1065.00
W12-F	PACl-Pb-1	1385.000	1399.000	1394.000	1393.000	7.300	0.520	PACl-Pb-1	W12-F	1393.00	1744.00			1393.00
W13-M	PACl-Pb-1	867.100	831.000	846.000	848.000	18.140	2.140	PACl-Pb-1	W13-M	848.00	1484.50			848.00
W13-W	PACl-Pb-1	369.900	435.400	455.800	420.400	44.890	10.680	PACl-Pb-1	W13-W	420.40	2273.20			420.40
W13-F	PACl-Pb-1	530.500	567.800	643.400	580.600	57.530	9.910	PACl-Pb-1	W13-F	580.60	713.25			580.60
W14-M	PACl-Pb-1	965.100	970.000	885.900	940.300	47.180	5.020	PACl-Pb-1	W14-M	940.30	915.00			940.30
W14-W	PACl-Pb-1	320.400	309.900	328.400	319.600	9.290	2.910	PACl-Pb-1	W14-W	319.60	402.45			319.60
W14-F	PACl-Pb-1	635.100	624.300	607.800	622.400	13.760	2.210	PACl-Pb-1	W14-F	622.40	820.70			622.40
W15-M	PACl-Pb-1	576.600	621.900	593.900	597.500	22.830	3.820	PACl-Pb-1	W15-M	597.50	751.95			597.50
W15-W	PACl-Pb-1	970.900	989.700	1009.000	989.900	19.120	1.930	PACl-Pb-1	W15-W	989.90	2185.45			989.90
W15-F	PACl-Pb-1	698.000	720.000	682.900	700.300	18.630	2.660	PACl-Pb-1	W15-F	700.30	583.10			700.30
W16-M	PACl-Pb-1	747.000	745.800	725.000	739.300	12.380	1.670	PACl-Pb-1	W16-M	739.30	763.20			739.30
W16-W	PACl-Pb-1	650.800	683.600	672.700	669.000	16.680	2.490	PACl-Pb-1	W16-W	669.00	1180.50			669.00
W16-F	PACl-Pb-1	1221.000	1297.000	1317.000	1278.000	50.500	3.950	PACl-Pb-1	W16-F	1278.00	1075.25			1278.00
W17-M	PACl-Pb-1	1370.000	1383.000	1374.000	1376.000	6.600	0.480	PACl-Pb-1	W17-M	1376.00	1127.20			1376.00
W17-W	PACl-Pb-1	770.700	778.000	788.600	779.400	8.940	1.150	PACl-Pb-1	W17-W	779.40	1156.20			779.40
W17-F	PACl-Pb-1	1040.000	1056.000	1053.000	1050.000	8.500	0.810	PACl-Pb-1	W17-F	1050.00	866.95			1050.00
W18-M	PACl-Pb-1	748.800	767.900	751.600	756.100	10.360	1.370	PACl-Pb-1	W18-M	756.10	513.55			756.10
W18-W	PACl-Pb-1	475.600	487.300	489.800	484.200	7.580	1.560	PACl-Pb-1	W18-W	484.20	745.10			484.20
W18-F	PACl-Pb-1	323.900	294.400	322.000	313.400	16.510	5.270	PACl-Pb-1	W18-F	313.40	277.85			313.40
W19-M	PACl-Pb-1	-	-	-	-	0.056	1.360	PACl-Pb-1	W19-M		275.20			-
W19-W	PACl-Pb-1	352.200	343.300	339.400	344.900	6.560	1.900	PACl-Pb-1	W19-W	344.90	287.75			344.90
W19-F	PACl-Pb-1	396.600	398.900	243.500	346.400	89.090	25.720	PACl-Pb-1	W19-F	346.40	292.25			346.40
W20-M	PACl-Pb-1	330.600	325.900	352.600	336.400	14.250	4.240	PACl-Pb-1	W20-M	336.40	319.10			336.40
W20-W	PACl-Pb-1	437.400	441.200	435.600	438.000	2.870	0.650	PACl-Pb-1	W20-W	438.00	369.90			438.00
W20-F	PACl-Pb-1	1236.000	1253.000	1233.000	1241.000	10.600	0.850	PACl-Pb-1	W20-F	1241.00	983.15			1241.00
W21-M	PACl-Pb-1	1366.000	1384.000	1370.000	1373.000	9.700	0.710	PACl-Pb-1	W21-M	1373.00	952.25			1373.00
W21-W	PACl-Pb-1	1076.000	1082.000	1069.000	1076.000	6.800	0.630	PACl-Pb-1	W21-W	1076.00	1133.50			1076.00
W21-F	PACl-Pb-1	649.600	705.400	715.600	690.200	35.520	5.150	PACl-Pb-1	W21-F	690.20	474.15			690.20
W22-M	PACl-Pb-1	150.200	125.200	109.400	128.300	20.610	16.070	PACl-Pb-1	W22-M	128.30	128.65			128.30
W22-W	PACl-Pb-1	573.000	583.800	587.400	581.600	7.290	1.250	PACl-Pb-1	W22-W	581.60	581.60			581.60
W22-F	PACl-Pb-1	502.400	523.000	516.000	513.800	10.500	2.040	PACl-Pb-1	W22-F	513.80	388.45			513.80
W23-M	PACl-Pb-1	788.500	781.000	839.000	802.800	31.580	3.930	PACl-Pb-1	W23-M	802.80	542.65			802.80
W23-W	PACl-Pb-1	466.400	460.600	473.400	466.800	6.380	1.370	PACl-Pb-1	W23-W	466.80	380.05			466.80
W23-F	PACl-Pb-1	298.600	300.700	315.200	304.800	9.050	2.987	PACl-Pb-1	W23-F	304.80	276.45			304.80
W24-M	PACl-Pb-1	370.500	419.500	410.500	400.100	26.080	6.520	PACl-Pb-1	W24-M	400.10	406.25			400.10
W24-W	PACl-Pb-1	33.700	345.900	332.400	337.400	7.440	2.200	PACl-Pb-1	W24-W	337.40	330.95			337.40
W24-F	PACl-Pb-1	372.100	389.300	386.200	382.500	9.190	2.400	PACl-Pb-1	W24-F	382.50	328.10			382.50
W25-M	PACl-Pb-1	283.300	295.700	264.000	281.000	15.960	5.680	PACl-Pb-1	W25-M	281.00	268.30			281.00
W25-W	PACl-Pb-1	-	-	-	-	-	-	PACl-Pb-1	W25-W		226.40			-
W25-F	PACl-Pb-1	-	-	-	-	-	-	PACl-Pb-1	W25-F		146.30			-
W26-M	PACl-Pb-1	707.600	678.200	716.400	700.700	20.020	2.860	PACl-Pb-1	W26-M	700.70	430.35			700.70
W26-W	PACl-Pb-1	151.600	177.400	150.800	159.900	15.180	9.490	PACl-Pb-1	W26-W	159.90	181.00			159.90
W26-F	PACl-Pb-1	171.700	203.200	316.300	230.400	76.020	33.000	PACl-Pb-1	W26-F	230.40	287.75			230.40
W27-M	PACl-Pb-1	255.500	228.400	239.200	241.000	13.640	5.660	PACl-Pb-1	W27-M	241.00	359.20			241.00

Week ID	Sample ID	Pb (Total) 1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Pb-2	14880.000	15480.000	15500.000	15280.000	351.100	2.300	PACl-Pb-2	W1-W	15280.00				15280.00
W1-F	PACl-Pb-2	6404.000	6318.000	6258.000	6327.000	73.500	1.160	PACl-Pb-2	W1-F	6327.00				6327.00
W2-M	PACl-Pb-2	3052.000	3066.000	3172.000	3097.000	65.900	2.130	PACl-Pb-2	W2-M	3097.00				3097.00
W2-W	PACl-Pb-2	1419.000	1461.000	1269.000	1383.000	101.100	7.310	PACl-Pb-2	W2-W	1383.00				1383.00
W2-F	PACl-Pb-2	977.100	553.400	1008.000	846.200	254.070	30.020	PACl-Pb-2	W2-F	846.20				846.20
W3-M	PACl-Pb-2	4258.000	4588.000	4213.000	4353.000	204.400	4.700	PACl-Pb-2	W3-M	4353.00				4353.00
W3-W	PACl-Pb-2	2039.000	1979.000	1851.000	1956.000	96.100	4.910	PACl-Pb-2	W3-W	1956.00				1956.00
W3-F	PACl-Pb-2	217.000	294.000	313.700	274.900	51.060	18.580	PACl-Pb-2	W3-F	274.90				274.90
W4-M	PACl-Pb-2	802.700	759.700	804.800	789.100	25.490	3.230	PACl-Pb-2	W4-M	789.10				789.10
W4-W	PACl-Pb-2	294.100	233.700	229.100	252.300	36.260	14.370	PACl-Pb-2	W4-W	252.30				252.30
W4-F	PACl-Pb-2	277.500	390.600	246.100	304.700	76.000	24.940	PACl-Pb-2	W4-F	304.70				304.70
W5-M	PACl-Pb-2	1064.000	1067.000	1049.000	1060.000	9.500	0.900	PACl-Pb-2	W5-M	1060.00				1060.00
W5-W	PACl-Pb-2	580.500	592.300	557.600	576.800	17.640	3.060	PACl-Pb-2	W5-W	576.80				576.80
W5-F	PACl-Pb-2	290.100	278.400	276.900	281.800	7.260	2.580	PACl-Pb-2	W5-F	281.80				281.80
W6-M	PACl-Pb-2	568.900	544.400	583.700	565.700	19.840	3.510	PACl-Pb-2	W6-M	565.70				565.70
W6-W	PACl-Pb-2	1074.000	1043.000	1094.000	1070.000	25.600	2.390	PACl-Pb-2	W6-W	1070.00				1070.00
W6-F	PACl-Pb-2	742.500	695.400	693.100	710.300	27.890	3.930	PACl-Pb-2	W6-F	710.30				710.30
W7-M	PACl-Pb-2	468.600	455.900	477.500	467.300	10.870	2.330	PACl-Pb-2	W7-M	467.30				467.30
W7-W	PACl-Pb-2	846.400	814.500	840.000	833.600	16.850	2.020	PACl-Pb-2	W7-W	833.60				833.60
W7-F	PACl-Pb-2	354.200	325.700	372.100	350.700	23.410	6.680	PACl-Pb-2	W7-F	350.70				350.70
W8-M	PACl-Pb-2	775.000	752.500	756.800	761.500	11.960	1.570	PACl-Pb-2	W8-M	761.50				761.50
W8-W	PACl-Pb-2	411.100	542.200	641.500	531.600	115.560	21.740	PACl-Pb-2	W8-W	531.60				531.60
W8-F	PACl-Pb-2	1136.000	1180.000	1125.000	1147.000	29.200	2.540	PACl-Pb-2	W8-F	1147.00				1147.00
W9-M	PACl-Pb-2	576.600	592.000	526.300	564.900	34.340	6.080	PACl-Pb-2	W9-M	564.90				564.90
W9-W	PACl-Pb-2	279.900	257.600	284.200	273.900	14.300	5.220	PACl-Pb-2	W9-W	273.90				273.90
W9-F	PACl-Pb-2	315.000	309.300	286.000	303.400	15.380	5.070	PACl-Pb-2	W9-F	303.40				303.40
W10-M	PACl-Pb-2	89.430	81.060	91.160	87.220	5.399	6.190	PACl-Pb-2	W10-M	87.22				87.22
W10-W	PACl-Pb-2	146.800	130.900	156.900	144.900	13.090	9.040	PACl-Pb-2	W10-W	144.90				144.90
W10-F	PACl-Pb-2	670.900	860.000	806.200	779.000	97.420	12.510	PACl-Pb-2	W10-F	779.00				779.00
W11-M	PACl-Pb-2	18240.000	17800.000	18600.000	18210.000	397.900	2.180	PACl-Pb-2	W11-M	18210.00				18210.00
W11-W	PACl-Pb-2	4125.000	4157.000	4337.000	4206.000	114.300	2.720	PACl-Pb-2	W11-W	4206.00				4206.00
W11-F	PACl-Pb-2	6655.000	6631.000	6660.000	6649.000	15.400	0.230	PACl-Pb-2	W11-F	6649.00				6649.00
W12-M	PACl-Pb-2	1755.000	1753.000	1745.000	1751.000	5.300	0.300	PACl-Pb-2	W12-M	1751.00				1751.00
W12-W	PACl-Pb-2	1800.000	1771.000	1805.000	1792.000	18.400	1.020	PACl-Pb-2	W12-W	1792.00				1792.00
W12-F	PACl-Pb-2	2076.000	2143.000	2067.000	2095.000	41.400	1.980	PACl-Pb-2	W12-F	2095.00				2095.00
W13-M	PACl-Pb-2	2175.000	2138.000	2050.000	2121.000	64.200	3.020	PACl-Pb-2	W13-M	2121.00				2121.00
W13-W	PACl-Pb-2	4106.000	4251.000	4022.000	4126.000	115.700	2.810	PACl-Pb-2	W13-W	4126.00				4126.00
W13-F	PACl-Pb-2	821.500	893.400	822.700	845.900	41.120	4.860	PACl-Pb-2	W13-F	845.90				845.90
W14-M	PACl-Pb-2	887.900	902.300	879.000	889.700	11.770	1.320	PACl-Pb-2	W14-M	889.70				889.70
W14-W	PACl-Pb-2	496.000	470.500	489.200	485.300	13.170	2.710	PACl-Pb-2	W14-W	485.30				485.30
W14-F	PACl-Pb-2	1012.000	1029.000	1015.000	1019.000	9.100	0.890	PACl-Pb-2	W14-F	1019.00				1019.00
W15-M	PACl-Pb-2	886.300	912.700	920.300	906.400	17.830	1.970	PACl-Pb-2	W15-M	906.40				906.40
W15-W	PACl-Pb-2	3483.000	3301.000	3358.000	3381.000	93.000	2.750	PACl-Pb-2	W15-W	3381.00				3381.00
W15-F	PACl-Pb-2	493.200	448.700	456.000	465.900	23.880	5.120	PACl-Pb-2	W15-F	465.90				465.90
W16-M	PACl-Pb-2	798.400	777.400	785.400	787.100	10.610	1.350	PACl-Pb-2	W16-M	787.10				787.10
W16-W	PACl-Pb-2	1653.000	1700.000	1723.000	1692.000	35.800	2.120	PACl-Pb-2	W16-W	1692.00				1692.00
W16-F	PACl-Pb-2	907.200	865.500	844.800	872.500	31.780	3.640	PACl-Pb-2	W16-F	872.50				872.50
W17-M	PACl-Pb-2	892.500	891.800	851.100	878.400	23.710	2.700	PACl-Pb-2	W17-M	878.40				878.40
W17-W	PACl-Pb-2	1520.000	1635.000	1444.000	1533.000	96.600	6.300	PACl-Pb-2	W17-W	1533.00				1533.00
W17-F	PACl-Pb-2	705.200	701.900	644.600	683.900	34.090	4.980	PACl-Pb-2	W17-F	683.90				683.90
W18-M	PACl-Pb-2	279.900	260.600	272.300	271.000	9.720	3.590	PACl-Pb-2	W18-M	271.00				271.00
W18-W	PACl-Pb-2	1025.000	988.200	1006.000	1006.000	18.400	1.830	PACl-Pb-2	W18-W	1006.00				1006.00
W18-F	PACl-Pb-2	235.100	237.700	254.000	242.300	10.260	4.240	PACl-Pb-2	W18-F	242.30				242.30
W19-M	PACl-Pb-2	265.000	275.000	285.600	275.200	10.310	3.750	PACl-Pb-2	W19-M	275.20				275.20
W19-W	PACl-Pb-2	215.900	246.100	229.900	230.600	15.080	6.540	PACl-Pb-2	W19-W	230.60				230.60
W19-F	PACl-Pb-2	223.600	244.100	246.600	238.100	12.590	5.290	PACl-Pb-2	W19-F	238.10				238.10
W20-M	PACl-Pb-2	311.800	304.100	289.700	301.800	11.240	3.720	PACl-Pb-2	W20-M	301.80				301.80
W20-W	PACl-Pb-2	305.700	291.100	308.600	301.800	9.400	3.120	PACl-Pb-2	W20-W	301.80				301.80
W20-F	PACl-Pb-2	732.500	710.600	732.800	725.300	12.710	1.750	PACl-Pb-2	W20-F	725.30				725.30
W21-M	PACl-Pb-2	539.800	531.300	523.500	531.500	8.140	1.530	PACl-Pb-2	W21-M	531.50				531.50
W21-W	PACl-Pb-2	1195.000	1183.000	1196.000	1191.000	6.900	0.580	PACl-Pb-2	W21-W	1191.00				1191.00
W21-F	PACl-Pb-2	261.100	266.200	246.900	258.100	10.020	3.880	PACl-Pb-2	W21-F	258.10				258.10
W22-M	PACl-Pb-2	134.600	119.600	132.800	129.000	8.160	6.330	PACl-Pb-2	W22-M	129.00				129.00
W22-W	PACl-Pb-2	-	-	-	-	-	-	PACl-Pb-2	W22-W					-
W22-F	PACl-Pb-2	270.000	254.800	264.000	263.100	7.870	2.990	PACl-Pb-2	W22-F	263.10				263.10
W23-M	PACl-Pb-2	272.900	293.200	281.300	282.500	10.210	3.610	PACl-Pb-2	W23-M	282.50				282.50
W23-W	PACl-Pb-2	318.300	292.500	269.000	293.300	24.660	8.410	PACl-Pb-2	W23-W	293.30				293.30
W23-F	PACl-Pb-2	255.700	246.100	242.500	248.100	6.810	2.750	PACl-Pb-2	W23-F	248.10				248.10
W24-M	PACl-Pb-2	391.800	419.100	426.200	412.400	18.180	4.410	PACl-Pb-2	W24-M	412.40				412.40
W24-W	PACl-Pb-2	299.600	351.300	322.600	324.500	25.870	7.970	PACl-Pb-2	W24-W	324.50				324.50
W24-F	PACl-Pb-2	275.100	263.600	282.400	273.700	9.480	3.460	PACl-Pb-2	W24-F	273.70				273.70
W25-M	PACl-Pb-2	291.100	278.600	197.100	255.600	51.060	19.970	PACl-Pb-2	W25-M	255.60				255.60
W25-W	PACl-Pb-2	228.600	217.000	233.500	226.400	8.480	3.750	PACl-Pb-2	W25-W	226.40				226.40
W25-F	PACl-Pb-2	154.300	153.800	130.600	146.300	13.540	9.260	PACl-Pb-2	W25-F	146.30				146.30
W26-M	PACl-Pb-2	150.900	152.900	176.200	160.000	14.080	8.800	PACl-Pb-2	W26-M	160.00				160.00
W26-W	PACl-Pb-2	206.000	207.800	192.400	202.100	8.430	4.170	PACl-Pb-2	W26-W	202.10				202.10
W26-F	PACl-Pb-2	359.800	322.500	352.900	345.100	19.880	5.760	PACl-Pb-2	W26-F	345.10				345.10
W27-M	PACl-Pb-2	480.200	490.500	461.600	477.400	14.670	3.070	PACl-Pb-2	W27-M	477.40				477.40

Table C1. Total and Dissolv

Week ID	Sample ID	Pb (Dissolved) 1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Cu-1							ALUM-Cu-1	W1-W			W1		
W1-F	ALUM-Cu-1							ALUM-Cu-1	W1-F			W2		
W2-M	ALUM-Cu-1							ALUM-Cu-1	W2-M			W3		
W2-W	ALUM-Cu-1							ALUM-Cu-1	W2-W			W4		
W2-F	ALUM-Cu-1							ALUM-Cu-1	W2-F			W5		
W3-M	ALUM-Cu-1							ALUM-Cu-1	W3-M			W6		
W3-W	ALUM-Cu-1							ALUM-Cu-1	W3-W			W7		
W3-F	ALUM-Cu-1							ALUM-Cu-1	W3-F			W8		
W4-M	ALUM-Cu-1							ALUM-Cu-1	W4-M			W9		
W4-W	ALUM-Cu-1							ALUM-Cu-1	W4-W			W10		
W4-F	ALUM-Cu-1							ALUM-Cu-1	W4-F			W11		
W5-M	ALUM-Cu-1							ALUM-Cu-1	W5-M			W12		
W5-W	ALUM-Cu-1							ALUM-Cu-1	W5-W			W13		
W5-F	ALUM-Cu-1							ALUM-Cu-1	W5-F			W14		
W6-M	ALUM-Cu-1							ALUM-Cu-1	W6-M			W15		
W6-W	ALUM-Cu-1							ALUM-Cu-1	W6-W			W16		
W6-F	ALUM-Cu-1							ALUM-Cu-1	W6-F			W17	20.84	
W7-M	ALUM-Cu-1							ALUM-Cu-1	W7-M			W18	26.44	
W7-W	ALUM-Cu-1							ALUM-Cu-1	W7-W			W19	28.28	
W7-F	ALUM-Cu-1							ALUM-Cu-1	W7-F			W20	33.94	
W8-M	ALUM-Cu-1							ALUM-Cu-1	W8-M			W21	49.19	
W8-W	ALUM-Cu-1							ALUM-Cu-1	W8-W			W22	24.47	
W8-F	ALUM-Cu-1							ALUM-Cu-1	W8-F			W23	27.03	
W9-M	ALUM-Cu-1							ALUM-Cu-1	W9-M			W24	19.44	
W9-W	ALUM-Cu-1							ALUM-Cu-1	W9-W			W25	12.30	
W9-F	ALUM-Cu-1							ALUM-Cu-1	W9-F			W26	16.73	
W10-M	ALUM-Cu-1							ALUM-Cu-1	W10-M			W27	25.38	
W10-W	ALUM-Cu-1							ALUM-Cu-1	W10-W					
W10-F	ALUM-Cu-1							ALUM-Cu-1	W10-F					
W11-M	ALUM-Cu-1							ALUM-Cu-1	W11-M					
W11-W	ALUM-Cu-1							ALUM-Cu-1	W11-W					
W11-F	ALUM-Cu-1							ALUM-Cu-1	W11-F					
W12-M	ALUM-Cu-1							ALUM-Cu-1	W12-M					
W12-W	ALUM-Cu-1							ALUM-Cu-1	W12-W					
W12-F	ALUM-Cu-1							ALUM-Cu-1	W12-F					
W13-M	ALUM-Cu-1							ALUM-Cu-1	W13-M					
W13-W	ALUM-Cu-1							ALUM-Cu-1	W13-W					
W13-F	ALUM-Cu-1							ALUM-Cu-1	W13-F					
W14-M	ALUM-Cu-1							ALUM-Cu-1	W14-M					
W14-W	ALUM-Cu-1							ALUM-Cu-1	W14-W					
W14-F	ALUM-Cu-1							ALUM-Cu-1	W14-F					
W15-M	ALUM-Cu-1							ALUM-Cu-1	W15-M					
W15-W	ALUM-Cu-1							ALUM-Cu-1	W15-W					
W15-F	ALUM-Cu-1							ALUM-Cu-1	W15-F					
W16-M	ALUM-Cu-1							ALUM-Cu-1	W16-M					
W16-W	ALUM-Cu-1							ALUM-Cu-1	W16-W					
W16-F	ALUM-Cu-1							ALUM-Cu-1	W16-F					
W17-M	ALUM-Cu-1	11.800	14.140	12.980	12.970	1.168	9.000	ALUM-Cu-1	W17-M	12.97	31.45			12.97
W17-W	ALUM-Cu-1							ALUM-Cu-1	W17-W	0.00	0.00			0.00
W17-F	ALUM-Cu-1	8.396	17.010	16.220	13.870	4.761	34.310	ALUM-Cu-1	W17-F	13.87	31.08			13.87
W18-M	ALUM-Cu-1	14.660	14.450	13.520	14.210	0.608	4.258	ALUM-Cu-1	W18-M	14.21	25.21			14.21
W18-W	ALUM-Cu-1	25.320	18.560	24.760	22.880	3.742	16.380	ALUM-Cu-1	W18-W	22.88	32.55			22.88
W18-F	ALUM-Cu-1	6.433	7.286	7.455	7.058	0.548	7.760	ALUM-Cu-1	W18-F	7.06	21.56			7.06
W19-M	ALUM-Cu-1	23.320	19.100	18.940	20.450	2.485	12.150	ALUM-Cu-1	W19-M	20.45	33.33			20.45
W19-W	ALUM-Cu-1	16.790	14.100	13.910	14.930	1.609	10.770	ALUM-Cu-1	W19-W	14.93	26.26			14.93
W19-F	ALUM-Cu-1	16.370	13.240	14.700	14.770	1.569	10.620	ALUM-Cu-1	W19-F	14.77	25.25			14.77
W20-M	ALUM-Cu-1	17.700	16.110	19.490	17.770	1.692	9.520	ALUM-Cu-1	W20-M	17.77	36.34			17.77
W20-W	ALUM-Cu-1	24.570	24.260	24.250	24.360	0.178	0.730	ALUM-Cu-1	W20-W	24.36	37.66			24.36
W20-F	ALUM-Cu-1	15.780	14.850	14.920	15.180	0.519	3.420	ALUM-Cu-1	W20-F	15.18	27.84			15.18
W21-M	ALUM-Cu-1	83.490	80.920	87.900	84.100	3.529	4.200	ALUM-Cu-1	W21-M	84.10	68.81			84.10
W21-W	ALUM-Cu-1	33.580	32.320	32.280	32.730	0.739	2.260	ALUM-Cu-1	W21-W	32.73	45.98			32.73
W21-F	ALUM-Cu-1	21.650	22.810	18.640	21.030	2.156	10.250	ALUM-Cu-1	W21-F	21.03	32.78			21.03
W22-M	ALUM-Cu-1	-0.518	-0.548	-0.684	-0.584	0.089	15.180	ALUM-Cu-1	W22-M	0.00	10.26			-0.58
W22-W	ALUM-Cu-1	21.980	22.750	21.730	22.150	0.530	2.390	ALUM-Cu-1	W22-W	22.15	34.36			22.15
W22-F	ALUM-Cu-1	21.920	22.050	21.470	21.810	0.306	1.400	ALUM-Cu-1	W22-F	21.81	28.79			21.81
W23-M	ALUM-Cu-1	26.400	37.120	25.050	29.520	6.617	22.410	ALUM-Cu-1	W23-M	29.52	35.01			29.52
W23-W	ALUM-Cu-1	15.480	17.480	15.470	16.140	1.158	7.180	ALUM-Cu-1	W23-W	16.14	24.36			16.14
W23-F	ALUM-Cu-1	16.160	16.230	13.540	15.310	1.535	10.030	ALUM-Cu-1	W23-F	15.31	21.74			15.31
W24-M	ALUM-Cu-1	23.470	24.070	35.700	27.750	6.897	24.860	ALUM-Cu-1	W24-M	27.75	29.30			27.75
W24-W	ALUM-Cu-1	18.980	9.819	11.650	13.480	4.849	35.960	ALUM-Cu-1	W24-W	13.48	15.55			13.48
W24-F	ALUM-Cu-1	15.650	14.620	14.560	14.914	0.613	4.100	ALUM-Cu-1	W24-F	14.91	13.46			14.91
W25-M	ALUM-Cu-1	28.740	28.150	27.060	27.980	0.851	3.040	ALUM-Cu-1	W25-M	27.98	21.48			27.98
W25-W	ALUM-Cu-1	8.155	8.147	4.218	6.840	2.271	33.200	ALUM-Cu-1	W25-W	6.84	8.50			6.84
W25-F	ALUM-Cu-1	10.380	4.544	6.897	7.273	2.935	40.360	ALUM-Cu-1	W25-F	7.27	6.91			7.27
W26-M	ALUM-Cu-1	14.630	12.930	12.510	13.360	1.121	8.390	ALUM-Cu-1	W26-M	13.36	9.47			13.36
W26-W	ALUM-Cu-1	10.600	10.680	9.048	10.110	0.920	9.100	ALUM-Cu-1	W26-W	10.11	7.22			10.11
W26-F	ALUM-Cu-1	34.290	31.820	34.410	33.510	1.462	4.360	ALUM-Cu-1	W26-F	33.51	33.51			33.51
W27-M	ALUM-Cu-1	40.020	34.700	38.330	37.680			ALUM-Cu-1	W27-M	37.68	25.38			37.68

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Cu-2							ALUM-Cu-2	W1-W					
W1-F	ALUM-Cu-2							ALUM-Cu-2	W1-F					
W2-M	ALUM-Cu-2							ALUM-Cu-2	W2-M					
W2-W	ALUM-Cu-2							ALUM-Cu-2	W2-W					
W2-F	ALUM-Cu-2							ALUM-Cu-2	W2-F					
W3-M	ALUM-Cu-2							ALUM-Cu-2	W3-M					
W3-W	ALUM-Cu-2							ALUM-Cu-2	W3-W					
W3-F	ALUM-Cu-2							ALUM-Cu-2	W3-F					
W4-M	ALUM-Cu-2							ALUM-Cu-2	W4-M					
W4-W	ALUM-Cu-2							ALUM-Cu-2	W4-W					
W4-F	ALUM-Cu-2							ALUM-Cu-2	W4-F					
W5-M	ALUM-Cu-2							ALUM-Cu-2	W5-M					
W5-W	ALUM-Cu-2							ALUM-Cu-2	W5-W					
W5-F	ALUM-Cu-2							ALUM-Cu-2	W5-F					
W6-M	ALUM-Cu-2							ALUM-Cu-2	W6-M					
W6-W	ALUM-Cu-2							ALUM-Cu-2	W6-W					
W6-F	ALUM-Cu-2							ALUM-Cu-2	W6-F					
W7-M	ALUM-Cu-2							ALUM-Cu-2	W7-M					
W7-W	ALUM-Cu-2							ALUM-Cu-2	W7-W					
W7-F	ALUM-Cu-2							ALUM-Cu-2	W7-F					
W8-M	ALUM-Cu-2							ALUM-Cu-2	W8-M					
W8-W	ALUM-Cu-2							ALUM-Cu-2	W8-W					
W8-F	ALUM-Cu-2							ALUM-Cu-2	W8-F					
W9-M	ALUM-Cu-2							ALUM-Cu-2	W9-M					
W9-W	ALUM-Cu-2							ALUM-Cu-2	W9-W					
W9-F	ALUM-Cu-2							ALUM-Cu-2	W9-F					
W10-M	ALUM-Cu-2							ALUM-Cu-2	W10-M					
W10-W	ALUM-Cu-2							ALUM-Cu-2	W10-W					
W10-F	ALUM-Cu-2							ALUM-Cu-2	W10-F					
W11-M	ALUM-Cu-2							ALUM-Cu-2	W11-M					
W11-W	ALUM-Cu-2							ALUM-Cu-2	W11-W					
W11-F	ALUM-Cu-2							ALUM-Cu-2	W11-F					
W12-M	ALUM-Cu-2							ALUM-Cu-2	W12-M					
W12-W	ALUM-Cu-2							ALUM-Cu-2	W12-W					
W12-F	ALUM-Cu-2							ALUM-Cu-2	W12-F					
W13-M	ALUM-Cu-2							ALUM-Cu-2	W13-M					
W13-W	ALUM-Cu-2							ALUM-Cu-2	W13-W					
W13-F	ALUM-Cu-2							ALUM-Cu-2	W13-F					
W14-M	ALUM-Cu-2							ALUM-Cu-2	W14-M					
W14-W	ALUM-Cu-2							ALUM-Cu-2	W14-W					
W14-F	ALUM-Cu-2							ALUM-Cu-2	W14-F					
W15-M	ALUM-Cu-2							ALUM-Cu-2	W15-M					
W15-W	ALUM-Cu-2							ALUM-Cu-2	W15-W					
W15-F	ALUM-Cu-2							ALUM-Cu-2	W15-F					
W16-M	ALUM-Cu-2							ALUM-Cu-2	W16-M					
W16-W	ALUM-Cu-2							ALUM-Cu-2	W16-W					
W16-F	ALUM-Cu-2							ALUM-Cu-2	W16-F					
W17-M	ALUM-Cu-2	50.890	50.110	48.780	49.930	1.070	2.140	ALUM-Cu-2	W17-M	49.93				49.93
W17-W	ALUM-Cu-2							ALUM-Cu-2	W17-W	0.00				0.00
W17-F	ALUM-Cu-2	48.520	48.480	47.860	48.280	0.367	0.760	ALUM-Cu-2	W17-F	48.28				48.28
W18-M	ALUM-Cu-2	36.970	35.400	36.280	36.210	0.787	2.170	ALUM-Cu-2	W18-M	36.21				36.21
W18-W	ALUM-Cu-2	40.570	36.840	49.260	42.220	6.373	15.090	ALUM-Cu-2	W18-W	42.22				42.22
W18-F	ALUM-Cu-2	34.600	35.290	38.290	36.060	1.962	5.440	ALUM-Cu-2	W18-F	36.06				36.06
W19-M	ALUM-Cu-2	45.620	46.270	46.730	46.210	0.561	1.210	ALUM-Cu-2	W19-M	46.21				46.21
W19-W	ALUM-Cu-2	38.600	37.870	36.280	37.580	1.186	3.160	ALUM-Cu-2	W19-W	37.58				37.58
W19-F	ALUM-Cu-2	37.870	34.060	35.250	35.730	1.950	5.460	ALUM-Cu-2	W19-F	35.73				35.73
W20-M	ALUM-Cu-2	54.970	55.410	54.320	54.900	0.550	1.000	ALUM-Cu-2	W20-M	54.90				54.90
W20-W	ALUM-Cu-2	51.730	52.510	48.610	50.950	2.067	4.060	ALUM-Cu-2	W20-W	50.95				50.95
W20-F	ALUM-Cu-2	39.230	40.550	41.700	40.490	1.238	3.060	ALUM-Cu-2	W20-F	40.49				40.49
W21-M	ALUM-Cu-2	54.200	53.510	52.830	53.510	0.684	1.280	ALUM-Cu-2	W21-M	53.51				53.51
W21-W	ALUM-Cu-2	58.750	58.770	60.150	59.220	0.801	1.350	ALUM-Cu-2	W21-W	59.22				59.22
W21-F	ALUM-Cu-2	43.870	45.540	44.180	44.530	0.887	1.990	ALUM-Cu-2	W21-F	44.53				44.53
W22-M	ALUM-Cu-2	21.510	20.300	19.740	20.520	0.903	4.400	ALUM-Cu-2	W22-M	20.52				20.52
W22-W	ALUM-Cu-2	46.270	45.620	47.790	46.560	1.114	2.390	ALUM-Cu-2	W22-W	46.56				46.56
W22-F	ALUM-Cu-2	34.280	38.160	34.870	35.770	2.092	5.850	ALUM-Cu-2	W22-F	35.77				35.77
W23-M	ALUM-Cu-2	38.490	46.420	36.570	40.490	5.223	12.900	ALUM-Cu-2	W23-M	40.49				40.49
W23-W	ALUM-Cu-2	41.750	27.570	23.380	32.570	7.963	24.450	ALUM-Cu-2	W23-W	32.57				32.57
W23-F	ALUM-Cu-2	29.900	29.570	25.050	28.170	2.712	9.630	ALUM-Cu-2	W23-F	28.17				28.17
W24-M	ALUM-Cu-2	31.790	30.300	30.460	30.850	0.815	2.640	ALUM-Cu-2	W24-M	30.85				30.85
W24-W	ALUM-Cu-2	16.510	18.060	18.250	17.610	0.953	5.410	ALUM-Cu-2	W24-W	17.61				17.61
W24-F	ALUM-Cu-2	12.990	13.500	9.554	12.010	2.146	17.860	ALUM-Cu-2	W24-F	12.01				12.01
W25-M	ALUM-Cu-2	18.260	12.590	14.070	14.970	2.945	19.670	ALUM-Cu-2	W25-M	14.97				14.97
W25-W	ALUM-Cu-2	11.180	8.340	10.980	10.160	1.583	15.570	ALUM-Cu-2	W25-W	10.16				10.16
W25-F	ALUM-Cu-2	4.835	6.529	6.296	6.553	1.731	26.410	ALUM-Cu-2	W25-F	6.55				6.55
W26-M	ALUM-Cu-2	5.898	5.940	4.927	5.588	0.573	10.260	ALUM-Cu-2	W26-M	5.59				5.59
W26-W	ALUM-Cu-2	5.180	3.784	4.000	4.321	0.751	17.390	ALUM-Cu-2	W26-W	4.32				4.32
W26-F	ALUM-Cu-2	-	-	-	-	-	-	ALUM-Cu-2	W26-F					-
W27-M	ALUM-Cu-2	13.750	12.750	12.750	13.080			ALUM-Cu-2	W27-M	13.08				13.08

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Pb-1							ALUM-Pb-1	W1-W			W1		
W1-F	ALUM-Pb-1							ALUM-Pb-1	W1-F			W2		
W2-M	ALUM-Pb-1							ALUM-Pb-1	W2-M			W3		
W2-W	ALUM-Pb-1							ALUM-Pb-1	W2-W			W4		
W2-F	ALUM-Pb-1							ALUM-Pb-1	W2-F			W5		
W3-M	ALUM-Pb-1							ALUM-Pb-1	W3-M			W6		
W3-W	ALUM-Pb-1							ALUM-Pb-1	W3-W			W7		
W3-F	ALUM-Pb-1							ALUM-Pb-1	W3-F			W8		
W4-M	ALUM-Pb-1							ALUM-Pb-1	W4-M			W9		
W4-W	ALUM-Pb-1							ALUM-Pb-1	W4-W			W10		
W4-F	ALUM-Pb-1							ALUM-Pb-1	W4-F			W11		
W5-M	ALUM-Pb-1							ALUM-Pb-1	W5-M			W12		
W5-W	ALUM-Pb-1							ALUM-Pb-1	W5-W			W13		
W5-F	ALUM-Pb-1							ALUM-Pb-1	W5-F			W14		
W6-M	ALUM-Pb-1							ALUM-Pb-1	W6-M			W15		
W6-W	ALUM-Pb-1							ALUM-Pb-1	W6-W			W16		
W6-F	ALUM-Pb-1							ALUM-Pb-1	W6-F			W17	103.65	
W7-M	ALUM-Pb-1							ALUM-Pb-1	W7-M			W18	123.51	
W7-W	ALUM-Pb-1							ALUM-Pb-1	W7-W			W19	129.80	
W7-F	ALUM-Pb-1							ALUM-Pb-1	W7-F			W20	141.91	
W8-M	ALUM-Pb-1							ALUM-Pb-1	W8-M			W21	125.71	
W8-W	ALUM-Pb-1							ALUM-Pb-1	W8-W			W22	158.66	
W8-F	ALUM-Pb-1							ALUM-Pb-1	W8-F			W23	138.12	
W9-M	ALUM-Pb-1							ALUM-Pb-1	W9-M			W24	153.06	
W9-W	ALUM-Pb-1							ALUM-Pb-1	W9-W			W25	126.92	
W9-F	ALUM-Pb-1							ALUM-Pb-1	W9-F			W26	99.84	
W10-M	ALUM-Pb-1							ALUM-Pb-1	W10-M			W27	93.72	
W10-W	ALUM-Pb-1							ALUM-Pb-1	W10-W					
W10-F	ALUM-Pb-1							ALUM-Pb-1	W10-F					
W11-M	ALUM-Pb-1							ALUM-Pb-1	W11-M					
W11-W	ALUM-Pb-1							ALUM-Pb-1	W11-W					
W11-F	ALUM-Pb-1							ALUM-Pb-1	W11-F					
W12-M	ALUM-Pb-1							ALUM-Pb-1	W12-M					
W12-W	ALUM-Pb-1							ALUM-Pb-1	W12-W					
W12-F	ALUM-Pb-1							ALUM-Pb-1	W12-F					
W13-M	ALUM-Pb-1							ALUM-Pb-1	W13-M					
W13-W	ALUM-Pb-1							ALUM-Pb-1	W13-W					
W13-F	ALUM-Pb-1							ALUM-Pb-1	W13-F					
W14-M	ALUM-Pb-1							ALUM-Pb-1	W14-M					
W14-W	ALUM-Pb-1							ALUM-Pb-1	W14-W					
W14-F	ALUM-Pb-1							ALUM-Pb-1	W14-F					
W15-M	ALUM-Pb-1							ALUM-Pb-1	W15-M					
W15-W	ALUM-Pb-1							ALUM-Pb-1	W15-W					
W15-F	ALUM-Pb-1							ALUM-Pb-1	W15-F					
W16-M	ALUM-Pb-1							ALUM-Pb-1	W16-M					
W16-W	ALUM-Pb-1							ALUM-Pb-1	W16-W					
W16-F	ALUM-Pb-1							ALUM-Pb-1	W16-F					
W17-M	ALUM-Pb-1	84.490	85.410	78.600	82.830	3.697	4.460	ALUM-Pb-1	W17-M	82.83	94.17			82.83
W17-W	ALUM-Pb-1	72.390	71.210	73.150	72.250	0.975	1.350	ALUM-Pb-1	W17-W	72.25	84.87			72.25
W17-F	ALUM-Pb-1	84.230	92.620	84.580	87.140	4.749	5.450	ALUM-Pb-1	W17-F	87.14	131.92			87.14
W18-M	ALUM-Pb-1	104.500	104.400	103.900	104.200	0.340	0.330	ALUM-Pb-1	W18-M	104.20	106.55			104.20
W18-W	ALUM-Pb-1	97.450	96.320	94.940	96.240	1.260	1.310	ALUM-Pb-1	W18-W	96.24	127.69			96.24
W18-F	ALUM-Pb-1	93.530	94.830	95.290	94.550	0.913	0.970	ALUM-Pb-1	W18-F	94.55	136.28			94.55
W19-M	ALUM-Pb-1	95.170	89.630	91.120	91.970	2.866	3.120	ALUM-Pb-1	W19-M	91.97	148.79			91.97
W19-W	ALUM-Pb-1	95.560	97.520	96.350	96.480	0.984	1.020	ALUM-Pb-1	W19-W	96.48	139.34			96.48
W19-F	ALUM-Pb-1	95.400	97.340	95.330	96.030	1.141	1.190	ALUM-Pb-1	W19-F	96.03	101.27			96.03
W20-M	ALUM-Pb-1	100.900	100.400	101.100	100.800	0.330	0.330	ALUM-Pb-1	W20-M	100.80	152.85			100.80
W20-W	ALUM-Pb-1	94.190	96.770	92.780	94.580	2.022	2.140	ALUM-Pb-1	W20-W	94.58	134.54			94.58
W20-F	ALUM-Pb-1	92.570	91.580	94.820	92.990	1.658	1.780	ALUM-Pb-1	W20-F	92.99	138.35			92.99
W21-M	ALUM-Pb-1	75.190	74.960	81.680	77.280	3.815	4.940	ALUM-Pb-1	W21-M	77.28	89.34			77.28
W21-W	ALUM-Pb-1	93.860	89.900	97.110	93.590	3.659	3.910	ALUM-Pb-1	W21-W	93.59	144.75			93.59
W21-F	ALUM-Pb-1	102.000	108.100	100.900	103.700	3.900	3.760	ALUM-Pb-1	W21-F	103.70	143.05			103.70
W22-M	ALUM-Pb-1	163.800	176.200	172.000	170.700	6.310	3.700	ALUM-Pb-1	W22-M	170.70	186.05			170.70
W22-W	ALUM-Pb-1	106.300	109.600	101.400	105.800	4.100	3.880	ALUM-Pb-1	W22-W	105.80	152.75			105.80
W22-F	ALUM-Pb-1	96.150	102.900	98.060	99.040	3.486	3.520	ALUM-Pb-1	W22-F	99.04	137.17			99.04
W23-M	ALUM-Pb-1	93.730	89.460	92.190	91.790	2.158	2.350	ALUM-Pb-1	W23-M	91.79	134.35			91.79
W23-W	ALUM-Pb-1	93.610	95.320	107.100	98.680	7.344	7.440	ALUM-Pb-1	W23-W	98.68	137.47			98.68
W23-F	ALUM-Pb-1	99.140	105.800	104.300	103.100	3.470	3.370	ALUM-Pb-1	W23-F	103.10	142.55			103.10
W24-M	ALUM-Pb-1	-	-	-	-	-	-	ALUM-Pb-1	W24-M		182.60			-
W24-W	ALUM-Pb-1	99.610	110.100	98.270	102.700	6.480	6.310	ALUM-Pb-1	W24-W	102.70	146.05			102.70
W24-F	ALUM-Pb-1	81.650	96.680	91.190	89.840	7.604	8.460	ALUM-Pb-1	W24-F	89.84	130.52			89.84
W25-M	ALUM-Pb-1	104.100	93.300	97.390	98.270	5.546	5.550	ALUM-Pb-1	W25-M	98.27	134.39			98.27
W25-W	ALUM-Pb-1	-	-	-	-	-	-	ALUM-Pb-1	W25-W		155.50			-
W25-F	ALUM-Pb-1	77.440	77.850	78.330	77.870	0.446	0.570	ALUM-Pb-1	W25-F	77.87	90.89			77.87
W26-M	ALUM-Pb-1	60.260	59.950	60.350	60.190	0.210	0.350	ALUM-Pb-1	W26-M	60.19	74.34			60.19
W26-W	ALUM-Pb-1	69.080	68.860	71.590	69.840	1.516	2.170	ALUM-Pb-1	W26-W	69.84	84.74			69.84
W26-F	ALUM-Pb-1	96.610	96.750	94.070	95.810	1.505	1.570	ALUM-Pb-1	W26-F	95.81	140.46			95.81
W27-M	ALUM-Pb-1	78.520	80.610	79.160	79.430			ALUM-Pb-1	W27-M	79.43	93.72			79.43

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	ALUM-Pb-2							ALUM-Pb-2	W1-W					
W1-F	ALUM-Pb-2							ALUM-Pb-2	W1-F					
W2-M	ALUM-Pb-2							ALUM-Pb-2	W2-M					
W2-W	ALUM-Pb-2							ALUM-Pb-2	W2-W					
W2-F	ALUM-Pb-2							ALUM-Pb-2	W2-F					
W3-M	ALUM-Pb-2							ALUM-Pb-2	W3-M					
W3-W	ALUM-Pb-2							ALUM-Pb-2	W3-W					
W3-F	ALUM-Pb-2							ALUM-Pb-2	W3-F					
W4-M	ALUM-Pb-2							ALUM-Pb-2	W4-M					
W4-W	ALUM-Pb-2							ALUM-Pb-2	W4-W					
W4-F	ALUM-Pb-2							ALUM-Pb-2	W4-F					
W5-M	ALUM-Pb-2							ALUM-Pb-2	W5-M					
W5-W	ALUM-Pb-2							ALUM-Pb-2	W5-W					
W5-F	ALUM-Pb-2							ALUM-Pb-2	W5-F					
W6-M	ALUM-Pb-2							ALUM-Pb-2	W6-M					
W6-W	ALUM-Pb-2							ALUM-Pb-2	W6-W					
W6-F	ALUM-Pb-2							ALUM-Pb-2	W6-F					
W7-M	ALUM-Pb-2							ALUM-Pb-2	W7-M					
W7-W	ALUM-Pb-2							ALUM-Pb-2	W7-W					
W7-F	ALUM-Pb-2							ALUM-Pb-2	W7-F					
W8-M	ALUM-Pb-2							ALUM-Pb-2	W8-M					
W8-W	ALUM-Pb-2							ALUM-Pb-2	W8-W					
W8-F	ALUM-Pb-2							ALUM-Pb-2	W8-F					
W9-M	ALUM-Pb-2							ALUM-Pb-2	W9-M					
W9-W	ALUM-Pb-2							ALUM-Pb-2	W9-W					
W9-F	ALUM-Pb-2							ALUM-Pb-2	W9-F					
W10-M	ALUM-Pb-2							ALUM-Pb-2	W10-M					
W10-W	ALUM-Pb-2							ALUM-Pb-2	W10-W					
W10-F	ALUM-Pb-2							ALUM-Pb-2	W10-F					
W11-M	ALUM-Pb-2							ALUM-Pb-2	W11-M					
W11-W	ALUM-Pb-2							ALUM-Pb-2	W11-W					
W11-F	ALUM-Pb-2							ALUM-Pb-2	W11-F					
W12-M	ALUM-Pb-2							ALUM-Pb-2	W12-M					
W12-W	ALUM-Pb-2							ALUM-Pb-2	W12-W					
W12-F	ALUM-Pb-2							ALUM-Pb-2	W12-F					
W13-M	ALUM-Pb-2							ALUM-Pb-2	W13-M					
W13-W	ALUM-Pb-2							ALUM-Pb-2	W13-W					
W13-F	ALUM-Pb-2							ALUM-Pb-2	W13-F					
W14-M	ALUM-Pb-2							ALUM-Pb-2	W14-M					
W14-W	ALUM-Pb-2							ALUM-Pb-2	W14-W					
W14-F	ALUM-Pb-2							ALUM-Pb-2	W14-F					
W15-M	ALUM-Pb-2							ALUM-Pb-2	W15-M					
W15-W	ALUM-Pb-2							ALUM-Pb-2	W15-W					
W15-F	ALUM-Pb-2							ALUM-Pb-2	W15-F					
W16-M	ALUM-Pb-2							ALUM-Pb-2	W16-M					
W16-W	ALUM-Pb-2							ALUM-Pb-2	W16-W					
W16-F	ALUM-Pb-2							ALUM-Pb-2	W16-F					
W17-M	ALUM-Pb-2	106.300	105.800	104.200	105.500	1.080	1.030	ALUM-Pb-2	W17-M	105.50				105.50
W17-W	ALUM-Pb-2	97.350	98.020	97.080	97.480	0.484	0.500	ALUM-Pb-2	W17-W	97.48				97.48
W17-F	ALUM-Pb-2	169.100	181.900	179.000	176.700	6.690	3.780	ALUM-Pb-2	W17-F	176.70				176.70
W18-M	ALUM-Pb-2	108.800	106.200	111.700	108.900	2.760	2.540	ALUM-Pb-2	W18-M	108.90				108.90
W18-W	ALUM-Pb-2	163.700	164.300	150.200	159.140	7.990	5.010	ALUM-Pb-2	W18-W	159.14				159.14
W18-F	ALUM-Pb-2	179.100	173.400	181.300	178.000	4.090	2.300	ALUM-Pb-2	W18-F	178.00				178.00
W19-M	ALUM-Pb-2	198.800	207.600	210.600	205.600	6.110	2.970	ALUM-Pb-2	W19-M	205.60				205.60
W19-W	ALUM-Pb-2	178.300	185.900	182.400	182.200	3.820	2.100	ALUM-Pb-2	W19-W	182.20				182.20
W19-F	ALUM-Pb-2	104.800	106.400	108.100	106.500	1.670	1.570	ALUM-Pb-2	W19-F	106.50				106.50
W20-M	ALUM-Pb-2	209.000	202.100	203.600	204.900	3.630	1.770	ALUM-Pb-2	W20-M	204.90				204.90
W20-W	ALUM-Pb-2	181.700	164.300	177.600	174.500	9.120	5.230	ALUM-Pb-2	W20-W	174.50				174.50
W20-F	ALUM-Pb-2	184.000	180.900	186.000	183.700	2.540	1.380	ALUM-Pb-2	W20-F	183.70				183.70
W21-M	ALUM-Pb-2	98.380	104.400	101.400	101.400	2.990	2.950	ALUM-Pb-2	W21-M	101.40				101.40
W21-W	ALUM-Pb-2	196.100	193.800	197.600	195.900	1.930	0.980	ALUM-Pb-2	W21-W	195.90				195.90
W21-F	ALUM-Pb-2	187.000	175.000	185.200	182.400	6.430	3.530	ALUM-Pb-2	W21-F	182.40				182.40
W22-M	ALUM-Pb-2	199.900	205.700	198.700	201.400	3.770	1.870	ALUM-Pb-2	W22-M	201.40				201.40
W22-W	ALUM-Pb-2	199.700	200.300	199.200	199.700	0.530	0.270	ALUM-Pb-2	W22-W	199.70				199.70
W22-F	ALUM-Pb-2	170.300	184.100	171.400	175.300	7.670	4.370	ALUM-Pb-2	W22-F	175.30				175.30
W23-M	ALUM-Pb-2	163.100	182.100	185.300	176.900	12.030	6.800	ALUM-Pb-2	W23-M	176.90				176.90
W23-W	ALUM-Pb-2	164.500	195.900	169.200	176.250	16.940	9.600	ALUM-Pb-2	W23-W	176.25				176.25
W23-F	ALUM-Pb-2	175.100	193.300	177.500	182.000	9.860	5.420	ALUM-Pb-2	W23-F	182.00				182.00
W24-M	ALUM-Pb-2	183.700	179.000	185.100	182.600	3.220	1.760	ALUM-Pb-2	W24-M	182.60				182.60
W24-W	ALUM-Pb-2	181.100	193.000	194.100	189.400	7.210	3.810	ALUM-Pb-2	W24-W	189.40				189.40
W24-F	ALUM-Pb-2	173.700	172.800	167.000	171.200	3.610	2.110	ALUM-Pb-2	W24-F	171.20				171.20
W25-M	ALUM-Pb-2	176.300	166.800	168.400	170.500	5.130	3.010	ALUM-Pb-2	W25-M	170.50				170.50
W25-W	ALUM-Pb-2	155.300	154.400	156.700	155.500	1.170	0.750	ALUM-Pb-2	W25-W	155.50				155.50
W25-F	ALUM-Pb-2	99.950	109.500	102.200	103.900	5.010	4.830	ALUM-Pb-2	W25-F	103.90				103.90
W26-M	ALUM-Pb-2	90.000	88.300	87.140	88.480	1.438	1.630	ALUM-Pb-2	W26-M	88.48				88.48
W26-W	ALUM-Pb-2	99.560	99.210	100.100	99.630	0.457	0.460	ALUM-Pb-2	W26-W	99.63				99.63
W26-F	ALUM-Pb-2	192.800	183.700	178.900	185.100	7.030	3.800	ALUM-Pb-2	W26-F	185.10				185.10
W27-M	ALUM-Pb-2	107.500	109.700	106.800	108.000			ALUM-Pb-2	W27-M	108.00				108.00

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Cu-1							FS-Cu-1	W1-W			W1		
W1-F	FS-Cu-1							FS-Cu-1	W1-F			W2		
W2-M	FS-Cu-1							FS-Cu-1	W2-M			W3		
W2-W	FS-Cu-1-Comp							FS-Cu-1-Comp	W2-W			W4		
W2-F	FS-Cu-1							FS-Cu-1	W2-F			W5		
W3-M	FS-Cu-1							FS-Cu-1	W3-M			W6		
W3-W	FS-Cu-1							FS-Cu-1	W3-W			W7		
W3-F	FS-Cu-1							FS-Cu-1	W3-F			W8		
W4-M	FS-Cu-1							FS-Cu-1	W4-M			W9		
W4-W	FS-Cu-1							FS-Cu-1	W4-W			W10		
W4-F	FS-Cu-1							FS-Cu-1	W4-F			W11		
W5-M	FS-Cu-1							FS-Cu-1	W5-M			W12		
W5-W	FS-Cu-1							FS-Cu-1	W5-W			W13		
W5-F	FS-Cu-1							FS-Cu-1	W5-F			W14		
W6-M	FS-Cu-1							FS-Cu-1	W6-M			W15		
W6-W	FS-Cu-1							FS-Cu-1	W6-W			W16		
W6-F	FS-Cu-1							FS-Cu-1	W6-F			W17	0.52	
W7-M	FS-Cu-1							FS-Cu-1	W7-M			W18	10.01	
W7-W	FS-Cu-1							FS-Cu-1	W7-W			W19	12.68	
W7-F	FS-Cu-1							FS-Cu-1	W7-F			W20	6.57	
W8-M	FS-Cu-1							FS-Cu-1	W8-M			W21	11.28	
W8-W	FS-Cu-1							FS-Cu-1	W8-W			W22	20.29	
W8-F	FS-Cu-1							FS-Cu-1	W8-F			W23	4.19	
W9-M	FS-Cu-1							FS-Cu-1	W9-M			W24	0.00	
W9-W	FS-Cu-1							FS-Cu-1	W9-W			W25	0.23	
W9-F	FS-Cu-1							FS-Cu-1	W9-F			W26	0.00	
W10-M	FS-Cu-1							FS-Cu-1	W10-M			W27	0.00	
W10-W	FS-Cu-1							FS-Cu-1	W10-W					
W10-F	FS-Cu-1							FS-Cu-1	W10-F					
W11-M	FS-Cu-1							FS-Cu-1	W11-M					
W11-W	FS-Cu-1							FS-Cu-1	W11-W					
W11-F	FS-Cu-1							FS-Cu-1	W11-F					
W12-M	FS-Cu-1							FS-Cu-1	W12-M					
W12-W	FS-Cu-1							FS-Cu-1	W12-W					
W12-F	FS-Cu-1							FS-Cu-1	W12-F					
W13-M	FS-Cu-1							FS-Cu-1	W13-M					
W13-W	FS-Cu-1							FS-Cu-1	W13-W					
W13-F	FS-Cu-1							FS-Cu-1	W13-F					
W14-M	FS-Cu-1							FS-Cu-1	W14-M					
W14-W	FS-Cu-1							FS-Cu-1	W14-W					
W14-F	FS-Cu-1							FS-Cu-1	W14-F					
W15-M	FS-Cu-1							FS-Cu-1	W15-M					
W15-W	FS-Cu-1							FS-Cu-1	W15-W					
W15-F	FS-Cu-1							FS-Cu-1	W15-F					
W16-M	FS-Cu-1							FS-Cu-1	W16-M					
W16-W	FS-Cu-1							FS-Cu-1	W16-W					
W16-F	FS-Cu-1							FS-Cu-1	W16-F					
W17-M	FS-Cu-1	-13.180	-14.400	-14.490	-14.020	0.737	5.250	FS-Cu-1	W17-M	0.00	0.00			-14.02
W17-W	FS-Cu-1							FS-Cu-1	W17-W	0.00	0.00			0.00
W17-F	FS-Cu-1	-0.748	-0.090	-0.123	-0.321	0.371	115.650	FS-Cu-1	W17-F	0.00	1.56			-0.32
W18-M	FS-Cu-1	-1.064	1.392	-0.703	-0.125	1.326	1061.850	FS-Cu-1	W18-M	0.00	7.23			-0.13
W18-W	FS-Cu-1	-0.871	-1.070	-1.132	-1.024	0.136	13.280	FS-Cu-1	W18-W	0.00	19.22			-1.02
W18-F	FS-Cu-1	-11.270	-11.300	-10.790	-11.120	0.284	2.550	FS-Cu-1	W18-F	0.00	3.59			-11.12
W19-M	FS-Cu-1	-5.500	-5.962	-6.933	-6.132	0.731	11.920	FS-Cu-1	W19-M	0.00	14.86			-6.13
W19-W	FS-Cu-1	-8.432	-10.110	-10.270	-9.606	1.020	10.620	FS-Cu-1	W19-W	0.00	3.77			-9.61
W19-F	FS-Cu-1	7.522	7.761	7.654	7.645	0.120	1.560	FS-Cu-1	W19-F	7.65	19.41			7.65
W20-M	FS-Cu-1	-4.951	-5.028	-4.686	-4.888	0.180	3.670	FS-Cu-1	W20-M	0.00	6.00			-4.89
W20-W	FS-Cu-1	-0.355	-0.301	0.263	-0.131	0.342	261.640	FS-Cu-1	W20-W	0.00	9.94			-0.13
W20-F	FS-Cu-1	-4.827	-4.797	-5.396	-5.007	0.338	6.750	FS-Cu-1	W20-F	0.00	3.76			-5.01
W21-M	FS-Cu-1	14.700	14.750	15.250	14.900	0.304	2.040	FS-Cu-1	W21-M	14.90	16.89			14.90
W21-W	FS-Cu-1	3.938	4.173	2.776	3.629	0.748	20.620	FS-Cu-1	W21-W	3.63	10.22			3.63
W21-F	FS-Cu-1	-2.036	-4.534	-4.442	-3.671	1.417	38.590	FS-Cu-1	W21-F	0.00	6.73			-3.67
W22-M	FS-Cu-1	32.320	31.800	36.900	33.670	2.807	8.340	FS-Cu-1	W22-M	33.67	43.71			33.67
W22-W	FS-Cu-1	1.844	0.407	0.683	0.978	0.762	77.970	FS-Cu-1	W22-W	0.98	9.02			0.98
W22-F	FS-Cu-1	2.881	-0.815	-0.831	0.412	2.139	519.410	FS-Cu-1	W22-F	0.41	8.14			0.41
W23-M	FS-Cu-1	1.786	0.078	1.577	1.147	0.931	81.220	FS-Cu-1	W23-M	1.15	3.86			1.15
W23-W	FS-Cu-1	-2.866	-4.486	-3.272	-3.541	0.843	23.800	FS-Cu-1	W23-W	0.00	3.47			-3.54
W23-F	FS-Cu-1	-0.379	-1.057	-1.593	-1.010	0.608	60.260	FS-Cu-1	W23-F	0.00	5.23			-1.01
W24-M	FS-Cu-1	-8.117	-8.359	-8.477	-8.318	0.184	2.210	FS-Cu-1	W24-M	0.00	0.00			-8.32
W24-W	FS-Cu-1	-0.631	-2.527	-0.708	-1.289	1.074	83.300	FS-Cu-1	W24-W	0.00	0.00			-1.29
W24-F	FS-Cu-1	-3.479	-5.463	-5.614	-4.852	1.191	24.550	FS-Cu-1	W24-F	0.00	0.00			-4.85
W25-M	FS-Cu-1	-3.811	-5.664	-5.719	-5.065	1.086	21.440	FS-Cu-1	W25-M	0.00	0.00			-5.07
W25-W	FS-Cu-1	-5.496	-6.416	-6.797	-6.236	0.669	10.730	FS-Cu-1	W25-W	0.00	0.00			-6.24
W25-F	FS-Cu-1	-3.983	-5.849	-5.951	-5.261	1.108	21.060	FS-Cu-1	W25-F	0.00	0.70			-5.26
W26-M	FS-Cu-1	-4.004	-5.704	-5.328	-5.012	0.893	17.810	FS-Cu-1	W26-M	0.00	0.00			-5.01
W26-W	FS-Cu-1	-3.757	-6.323	-6.700	-5.593	1.601	28.620	FS-Cu-1	W26-W	0.00	0.00			-5.59
W26-F	FS-Cu-1	-1.815	-2.227	-2.224	-2.089	0.237	11.340	FS-Cu-1	W26-F	0.00	0.00			-2.09
W27-M	FS-Cu-1	-2.668	-4.671	-4.710	-4.016			FS-Cu-1	W27-M	0.00	0.00			-4.02

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Cu-2							FS-Cu-2	W1-W					
W1-F	FS-Cu-2							FS-Cu-2	W1-F					
W2-M	FS-Cu-2							FS-Cu-2	W2-M					
W2-W	FS-Cu-2-Comp							FS-Cu-2-Comp	W2-W					
W2-F	FS-Cu-2							FS-Cu-2	W2-F					
W3-M	FS-Cu-2							FS-Cu-2	W3-M					
W3-W	FS-Cu-2							FS-Cu-2	W3-W					
W3-F	FS-Cu-2							FS-Cu-2	W3-F					
W4-M	FS-Cu-2							FS-Cu-2	W4-M					
W4-W	FS-Cu-2							FS-Cu-2	W4-W					
W4-F	FS-Cu-2							FS-Cu-2	W4-F					
W5-M	FS-Cu-2							FS-Cu-2	W5-M					
W5-W	FS-Cu-2							FS-Cu-2	W5-W					
W5-F	FS-Cu-2							FS-Cu-2	W5-F					
W6-M	FS-Cu-2							FS-Cu-2	W6-M					
W6-W	FS-Cu-2							FS-Cu-2	W6-W					
W6-F	FS-Cu-2							FS-Cu-2	W6-F					
W7-M	FS-Cu-2							FS-Cu-2	W7-M					
W7-W	FS-Cu-2							FS-Cu-2	W7-W					
W7-F	FS-Cu-2							FS-Cu-2	W7-F					
W8-M	FS-Cu-2							FS-Cu-2	W8-M					
W8-W	FS-Cu-2							FS-Cu-2	W8-W					
W8-F	FS-Cu-2							FS-Cu-2	W8-F					
W9-M	FS-Cu-2							FS-Cu-2	W9-M					
W9-W	FS-Cu-2							FS-Cu-2	W9-W					
W9-F	FS-Cu-2							FS-Cu-2	W9-F					
W10-M	FS-Cu-2							FS-Cu-2	W10-M					
W10-W	FS-Cu-2							FS-Cu-2	W10-W					
W10-F	FS-Cu-2							FS-Cu-2	W10-F					
W11-M	FS-Cu-2							FS-Cu-2	W11-M					
W11-W	FS-Cu-2							FS-Cu-2	W11-W					
W11-F	FS-Cu-2							FS-Cu-2	W11-F					
W12-M	FS-Cu-2							FS-Cu-2	W12-M					
W12-W	FS-Cu-2							FS-Cu-2	W12-W					
W12-F	FS-Cu-2							FS-Cu-2	W12-F					
W13-M	FS-Cu-2							FS-Cu-2	W13-M					
W13-W	FS-Cu-2							FS-Cu-2	W13-W					
W13-F	FS-Cu-2							FS-Cu-2	W13-F					
W14-M	FS-Cu-2							FS-Cu-2	W14-M					
W14-W	FS-Cu-2							FS-Cu-2	W14-W					
W14-F	FS-Cu-2							FS-Cu-2	W14-F					
W15-M	FS-Cu-2							FS-Cu-2	W15-M					
W15-W	FS-Cu-2							FS-Cu-2	W15-W					
W15-F	FS-Cu-2							FS-Cu-2	W15-F					
W16-M	FS-Cu-2							FS-Cu-2	W16-M					
W16-W	FS-Cu-2							FS-Cu-2	W16-W					
W16-F	FS-Cu-2							FS-Cu-2	W16-F					
W17-M	FS-Cu-2	-6.831	-7.425	-7.703	-7.320	0.446	6.090	FS-Cu-2	W17-M	0.00				-7.32
W17-W	FS-Cu-2							FS-Cu-2	W17-W	0.00				0.00
W17-F	FS-Cu-2	1.303	1.939	6.140	3.128	2.629	84.040	FS-Cu-2	W17-F	3.13				3.13
W18-M	FS-Cu-2	11.680	15.940	15.770	14.460	2.412	16.680	FS-Cu-2	W18-M	14.46				14.46
W18-W	FS-Cu-2	38.300	38.330	38.700	38.440	0.222	0.580	FS-Cu-2	W18-W	38.44				38.44
W18-F	FS-Cu-2	6.739	7.750	7.031	7.173	0.521	7.260	FS-Cu-2	W18-F	7.17				7.17
W19-M	FS-Cu-2	28.750	29.210	31.210	29.720	1.309	4.410	FS-Cu-2	W19-M	29.72				29.72
W19-W	FS-Cu-2	7.227	7.976	7.412	7.538	0.390	5.170	FS-Cu-2	W19-W	7.54				7.54
W19-F	FS-Cu-2	33.240	33.800	26.490	31.180	4.069	13.050	FS-Cu-2	W19-F	31.18				31.18
W20-M	FS-Cu-2	11.530	12.740	11.730	12.000	0.651	5.420	FS-Cu-2	W20-M	12.00				12.00
W20-W	FS-Cu-2	18.550	20.700	20.340	19.870	1.151	5.800	FS-Cu-2	W20-W	19.87				19.87
W20-F	FS-Cu-2	8.735	6.689	7.135	7.520	1.076	14.310	FS-Cu-2	W20-F	7.52				7.52
W21-M	FS-Cu-2	19.390	19.810	17.410	18.870	1.281	6.790	FS-Cu-2	W21-M	18.87				18.87
W21-W	FS-Cu-2	17.870	16.710	15.850	16.810	1.015	6.040	FS-Cu-2	W21-W	16.81				16.81
W21-F	FS-Cu-2	11.930	17.300	11.120	13.450	3.359	24.980	FS-Cu-2	W21-F	13.45				13.45
W22-M	FS-Cu-2	52.360	54.060	54.810	53.750	1.256	2.340	FS-Cu-2	W22-M	53.75				53.75
W22-W	FS-Cu-2	15.990	18.300	16.890	17.060	1.165	6.830	FS-Cu-2	W22-W	17.06				17.06
W22-F	FS-Cu-2	14.610	16.640	16.320	15.860	1.094	6.900	FS-Cu-2	W22-F	15.86				15.86
W23-M	FS-Cu-2	7.230	6.305	6.190	6.575	0.570	8.670	FS-Cu-2	W23-M	6.58				6.58
W23-W	FS-Cu-2	6.668	6.389	7.756	6.938	0.722	10.410	FS-Cu-2	W23-W	6.94				6.94
W23-F	FS-Cu-2	9.623	10.620	11.120	10.450	0.762	7.290	FS-Cu-2	W23-F	10.45				10.45
W24-M	FS-Cu-2	-1.147	-1.377	-0.988	-1.171	0.195	16.680	FS-Cu-2	W24-M	0.00				-1.17
W24-W	FS-Cu-2	-3.386	-1.955	-3.592	-2.978	0.892	29.950	FS-Cu-2	W24-W	0.00				-2.98
W24-F	FS-Cu-2	-1.148	-1.751	-1.456	-1.452	0.302	20.780	FS-Cu-2	W24-F	0.00				-1.45
W25-M	FS-Cu-2	-1.025	-3.126	-2.750	-2.300	1.120	48.690	FS-Cu-2	W25-M	0.00				-2.30
W25-W	FS-Cu-2	-0.945	-0.621	1.081	-0.162	1.088	671.480	FS-Cu-2	W25-W	0.00				-0.16
W25-F	FS-Cu-2	1.988	1.168	1.056	1.404	0.509	36.270	FS-Cu-2	W25-F	1.40				1.40
W26-M	FS-Cu-2	-5.130	-5.497	-5.260	-5.295	0.186	3.510	FS-Cu-2	W26-M	0.00				-5.30
W26-W	FS-Cu-2	-5.752	-5.652	-5.278	-5.561	0.250	4.490	FS-Cu-2	W26-W	0.00				-5.56
W26-F	FS-Cu-2	-0.414	-0.117	-0.597	-0.376	0.242	64.470	FS-Cu-2	W26-F	0.00				-0.38
W27-M	FS-Cu-2	-2.881	-3.737	-2.836	-3.151			FS-Cu-2	W27-M	0.00				-3.15

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Pb-1							FS-Pb-1	W1-W			W1		
W1-F	FS-Pb-1							FS-Pb-1	W1-F			W2		
W2-M	FS-Pb-1							FS-Pb-1	W2-M			W3		
W2-W	FS-Pb-1-Comp							FS-Pb-1-Comp	W2-W			W4		
W2-F	FS-Pb-1							FS-Pb-1	W2-F			W5		
W3-M	FS-Pb-1							FS-Pb-1	W3-M			W6		
W3-W	FS-Pb-1							FS-Pb-1	W3-W			W7		
W3-F	FS-Pb-1							FS-Pb-1	W3-F			W8		
W4-M	FS-Pb-1							FS-Pb-1	W4-M			W9		
W4-W	FS-Pb-1							FS-Pb-1	W4-W			W10		
W4-F	FS-Pb-1							FS-Pb-1	W4-F			W11		
W5-M	FS-Pb-1							FS-Pb-1	W5-M			W12		
W5-W	FS-Pb-1							FS-Pb-1	W5-W			W13		
W5-F	FS-Pb-1							FS-Pb-1	W5-F			W14		
W6-M	FS-Pb-1							FS-Pb-1	W6-M			W15		
W6-W	FS-Pb-1							FS-Pb-1	W6-W			W16		
W6-F	FS-Pb-1							FS-Pb-1	W6-F			W17	197.67	
W7-M	FS-Pb-1							FS-Pb-1	W7-M			W18	213.23	
W7-W	FS-Pb-1							FS-Pb-1	W7-W			W19	236.72	
W7-F	FS-Pb-1							FS-Pb-1	W7-F			W20	195.92	
W8-M	FS-Pb-1							FS-Pb-1	W8-M			W21	214.82	
W8-W	FS-Pb-1							FS-Pb-1	W8-W			W22	258.85	
W8-F	FS-Pb-1							FS-Pb-1	W8-F			W23	221.64	
W9-M	FS-Pb-1							FS-Pb-1	W9-M			W24	195.50	
W9-W	FS-Pb-1							FS-Pb-1	W9-W			W25	179.13	
W9-F	FS-Pb-1							FS-Pb-1	W9-F			W26	137.64	
W10-M	FS-Pb-1							FS-Pb-1	W10-M			W27	130.55	
W10-W	FS-Pb-1							FS-Pb-1	W10-W					
W10-F	FS-Pb-1							FS-Pb-1	W10-F					
W11-M	FS-Pb-1							FS-Pb-1	W11-M					
W11-W	FS-Pb-1							FS-Pb-1	W11-W					
W11-F	FS-Pb-1							FS-Pb-1	W11-F					
W12-M	FS-Pb-1							FS-Pb-1	W12-M					
W12-W	FS-Pb-1							FS-Pb-1	W12-W					
W12-F	FS-Pb-1							FS-Pb-1	W12-F					
W13-M	FS-Pb-1							FS-Pb-1	W13-M					
W13-W	FS-Pb-1							FS-Pb-1	W13-W					
W13-F	FS-Pb-1							FS-Pb-1	W13-F					
W14-M	FS-Pb-1							FS-Pb-1	W14-M					
W14-W	FS-Pb-1							FS-Pb-1	W14-W					
W14-F	FS-Pb-1							FS-Pb-1	W14-F					
W15-M	FS-Pb-1							FS-Pb-1	W15-M					
W15-W	FS-Pb-1							FS-Pb-1	W15-W					
W15-F	FS-Pb-1							FS-Pb-1	W15-F					
W16-M	FS-Pb-1							FS-Pb-1	W16-M					
W16-W	FS-Pb-1							FS-Pb-1	W16-W					
W16-F	FS-Pb-1							FS-Pb-1	W16-F					
W17-M	FS-Pb-1	152.800	162.900	158.800	158.200	5.080	3.210	FS-Pb-1	W17-M	158.20	186.05			158.20
W17-W	FS-Pb-1	109.100	105.600	110.000	108.200	2.340	2.160	FS-Pb-1	W17-W	108.20	139.00			108.20
W17-F	FS-Pb-1	210.300	211.100	199.500	207.000	6.460	3.120	FS-Pb-1	W17-F	207.00	267.95			207.00
W18-M	FS-Pb-1	186.200	190.100	1783.300	186.500	3.380	1.810	FS-Pb-1	W18-M	186.50	200.90			186.50
W18-W	FS-Pb-1	202.300	204.100	199.600	202.000	2.250	1.110	FS-Pb-1	W18-W	202.00	211.10			202.00
W18-F	FS-Pb-1	103.700	104.800	104.300	104.300	0.550	0.530	FS-Pb-1	W18-F	104.30	227.70			104.30
W19-M	FS-Pb-1	182.900	182.600	186.100	183.900	1.940	1.060	FS-Pb-1	W19-M	183.90	267.45			183.90
W19-W	FS-Pb-1	179.600	176.500	176.200	177.400	1.900	1.070	FS-Pb-1	W19-W	177.40	287.35			177.40
W19-F	FS-Pb-1	107.700	105.400	104.400	105.800	1.700	1.610	FS-Pb-1	W19-F	105.80	155.35			105.80
W20-M	FS-Pb-1	108.100	107.500	110.300	108.700	1.490	1.370	FS-Pb-1	W20-M	108.70	159.70			108.70
W20-W	FS-Pb-1	203.700	206.100	206.100	205.300	1.400	0.680	FS-Pb-1	W20-W	205.30	275.95			205.30
W20-F	FS-Pb-1	105.200	107.400	107.700	106.800	1.360	1.270	FS-Pb-1	W20-F	106.80	152.10			106.80
W21-M	FS-Pb-1	98.320	93.080	104.400	98.590	5.661	5.740	FS-Pb-1	W21-M	98.59	151.10			98.59
W21-W	FS-Pb-1	201.400	211.600	198.500	203.800	6.880	3.380	FS-Pb-1	W21-W	203.80	212.80			203.80
W21-F	FS-Pb-1	206.800	202.200	199.200	202.700	3.840	1.890	FS-Pb-1	W21-F	202.70	280.55			202.70
W22-M	FS-Pb-1	107.500	103.500	105.300	105.400	2.050	1.950	FS-Pb-1	W22-M	105.40	143.35			105.40
W22-W	FS-Pb-1	352.500	328.400	327.300	336.100	14.270	4.250	FS-Pb-1	W22-W	336.10	362.85			336.10
W22-F	FS-Pb-1	207.600	196.200	197.200	200.400	6.310	3.150	FS-Pb-1	W22-F	200.40	270.35			200.40
W23-M	FS-Pb-1	193.600	197.500	210.500	200.500	8.850	4.410	FS-Pb-1	W23-M	200.50	202.15			200.50
W23-W	FS-Pb-1	179.700	177.000	169.600	175.140	5.210	2.970	FS-Pb-1	W23-W	175.14	188.67			175.14
W23-F	FS-Pb-1	186.300	213.700	190.000	196.700	14.840	7.550	FS-Pb-1	W23-F	196.70	274.10			196.70
W24-M	FS-Pb-1	163.100	165.100	153.900	160.700	5.960	3.710	FS-Pb-1	W24-M	160.70	178.75			160.70
W24-W	FS-Pb-1	185.300	186.600	187.500	186.500	1.110	0.600	FS-Pb-1	W24-W	186.50	202.70			186.50
W24-F	FS-Pb-1	208.200	203.800	188.600	200.200	10.250	5.120	FS-Pb-1	W24-F	200.20	205.05			200.20
W25-M	FS-Pb-1	174.300	193.500	174.700	180.800	11.000	6.090	FS-Pb-1	W25-M	180.80	243.25			180.80
W25-W	FS-Pb-1	209.800	199.400	196.200	201.800	7.140	3.540	FS-Pb-1	W25-W	201.80	191.15			201.80
W25-F	FS-Pb-1	99.100	97.630	98.660	98.460	0.757	0.770	FS-Pb-1	W25-F	98.46	102.98			98.46
W26-M	FS-Pb-1	93.720	97.990	96.700	96.130	2.192	2.280	FS-Pb-1	W26-M	96.13	101.72			96.13
W26-W	FS-Pb-1	102.100	107.200	106.700	105.300	2.780	2.640	FS-Pb-1	W26-W	105.30	103.10			105.30
W26-F	FS-Pb-1	195.300	199.100	208.000	200.800	6.550	3.260	FS-Pb-1	W26-F	200.80	208.10			200.80
W27-M	FS-Pb-1	152.100	158.300	153.000	154.500			FS-Pb-1	W27-M	154.50	130.55			154.50

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	FS-Pb-2							FS-Pb-2	W1-W					
W1-F	FS-Pb-2							FS-Pb-2	W1-F					
W2-M	FS-Pb-2							FS-Pb-2	W2-M					
W2-W	FS-Pb-2-Comp							FS-Pb-2-Comp	W2-W					
W2-F	FS-Pb-2							FS-Pb-2	W2-F					
W3-M	FS-Pb-2							FS-Pb-2	W3-M					
W3-W	FS-Pb-2							FS-Pb-2	W3-W					
W3-F	FS-Pb-2							FS-Pb-2	W3-F					
W4-M	FS-Pb-2							FS-Pb-2	W4-M					
W4-W	FS-Pb-2							FS-Pb-2	W4-W					
W4-F	FS-Pb-2							FS-Pb-2	W4-F					
W5-M	FS-Pb-2							FS-Pb-2	W5-M					
W5-W	FS-Pb-2							FS-Pb-2	W5-W					
W5-F	FS-Pb-2							FS-Pb-2	W5-F					
W6-M	FS-Pb-2							FS-Pb-2	W6-M					
W6-W	FS-Pb-2							FS-Pb-2	W6-W					
W6-F	FS-Pb-2							FS-Pb-2	W6-F					
W7-M	FS-Pb-2							FS-Pb-2	W7-M					
W7-W	FS-Pb-2							FS-Pb-2	W7-W					
W7-F	FS-Pb-2							FS-Pb-2	W7-F					
W8-M	FS-Pb-2							FS-Pb-2	W8-M					
W8-W	FS-Pb-2							FS-Pb-2	W8-W					
W8-F	FS-Pb-2							FS-Pb-2	W8-F					
W9-M	FS-Pb-2							FS-Pb-2	W9-M					
W9-W	FS-Pb-2							FS-Pb-2	W9-W					
W9-F	FS-Pb-2							FS-Pb-2	W9-F					
W10-M	FS-Pb-2							FS-Pb-2	W10-M					
W10-W	FS-Pb-2							FS-Pb-2	W10-W					
W10-F	FS-Pb-2							FS-Pb-2	W10-F					
W11-M	FS-Pb-2							FS-Pb-2	W11-M					
W11-W	FS-Pb-2							FS-Pb-2	W11-W					
W11-F	FS-Pb-2							FS-Pb-2	W11-F					
W12-M	FS-Pb-2							FS-Pb-2	W12-M					
W12-W	FS-Pb-2							FS-Pb-2	W12-W					
W12-F	FS-Pb-2							FS-Pb-2	W12-F					
W13-M	FS-Pb-2							FS-Pb-2	W13-M					
W13-W	FS-Pb-2							FS-Pb-2	W13-W					
W13-F	FS-Pb-2							FS-Pb-2	W13-F					
W14-M	FS-Pb-2							FS-Pb-2	W14-M					
W14-W	FS-Pb-2							FS-Pb-2	W14-W					
W14-F	FS-Pb-2							FS-Pb-2	W14-F					
W15-M	FS-Pb-2							FS-Pb-2	W15-M					
W15-W	FS-Pb-2							FS-Pb-2	W15-W					
W15-F	FS-Pb-2							FS-Pb-2	W15-F					
W16-M	FS-Pb-2							FS-Pb-2	W16-M					
W16-W	FS-Pb-2							FS-Pb-2	W16-W					
W16-F	FS-Pb-2							FS-Pb-2	W16-F					
W17-M	FS-Pb-2	195.900	228.700	217.200	213.900	16.650	7.780	FS-Pb-2	W17-M	213.90				213.90
W17-W	FS-Pb-2	176.700	166.700	165.900	169.800	5.980	3.520	FS-Pb-2	W17-W	169.80				169.80
W17-F	FS-Pb-2	305.600	345.100	336.100	328.900	20.700	6.290	FS-Pb-2	W17-F	328.90				328.90
W18-M	FS-Pb-2	219.500	216.500	210.000	215.300	4.860	2.260	FS-Pb-2	W18-M	215.30				215.30
W18-W	FS-Pb-2	218.800	219.400	222.300	220.200	1.900	0.860	FS-Pb-2	W18-W	220.20				220.20
W18-F	FS-Pb-2	347.100	349.300	357.000	351.100	5.200	1.480	FS-Pb-2	W18-F	351.10				351.10
W19-M	FS-Pb-2	346.900	352.300	353.800	351.000	3.590	1.020	FS-Pb-2	W19-M	351.00				351.00
W19-W	FS-Pb-2	392.400	404.700	394.800	397.300	6.520	1.640	FS-Pb-2	W19-W	397.30				397.30
W19-F	FS-Pb-2	203.600	207.100	203.900	204.900	1.960	0.960	FS-Pb-2	W19-F	204.90				204.90
W20-M	FS-Pb-2	208.100	211.200	212.700	210.700	2.350	1.120	FS-Pb-2	W20-M	210.70				210.70
W20-W	FS-Pb-2	336.700	356.100	346.900	346.600	9.740	2.810	FS-Pb-2	W20-W	346.60				346.60
W20-F	FS-Pb-2	206.800	198.900	186.600	197.400	10.170	5.150	FS-Pb-2	W20-F	197.40				197.40
W21-M	FS-Pb-2	208.900	203.800	198.200	203.600	5.360	2.630	FS-Pb-2	W21-M	203.60				203.60
W21-W	FS-Pb-2	215.800	233.000	216.500	221.800	9.730	4.390	FS-Pb-2	W21-W	221.80				221.80
W21-F	FS-Pb-2	351.000	355.000	369.200	358.400	9.580	2.670	FS-Pb-2	W21-F	358.40				358.40
W22-M	FS-Pb-2	206.700	185.900	151.300	181.300	27.960	15.430	FS-Pb-2	W22-M	181.30				181.30
W22-W	FS-Pb-2	394.200	392.200	382.500	389.600	6.240	1.600	FS-Pb-2	W22-W	389.60				389.60
W22-F	FS-Pb-2	365.600	323.600	331.600	340.300	22.290	6.550	FS-Pb-2	W22-F	340.30				340.30
W23-M	FS-Pb-2	218.400	198.100	194.800	203.800	12.810	6.290	FS-Pb-2	W23-M	203.80				203.80
W23-W	FS-Pb-2	197.100	194.800	214.600	202.200	10.840	5.360	FS-Pb-2	W23-W	202.20				202.20
W23-F	FS-Pb-2	365.100	325.300	364.200	351.500	22.730	6.470	FS-Pb-2	W23-F	351.50				351.50
W24-M	FS-Pb-2	204.200	200.500	185.900	196.800	9.690	4.920	FS-Pb-2	W24-M	196.80				196.80
W24-W	FS-Pb-2	218.500	216.000	222.000	218.900	3.020	1.380	FS-Pb-2	W24-W	218.90				218.90
W24-F	FS-Pb-2	206.700	217.000	206.000	209.900	6.140	2.920	FS-Pb-2	W24-F	209.90				209.90
W25-M	FS-Pb-2	274.500	293.400	349.100	305.700	38.780	12.690	FS-Pb-2	W25-M	305.70				305.70
W25-W	FS-Pb-2	198.000	167.400	176.200	180.500	15.770	8.730	FS-Pb-2	W25-W	180.50				180.50
W25-F	FS-Pb-2	107.400	108.400	106.700	107.500	0.860	0.800	FS-Pb-2	W25-F	107.50				107.50
W26-M	FS-Pb-2	108.100	105.700	108.100	107.300	1.360	1.270	FS-Pb-2	W26-M	107.30				107.30
W26-W	FS-Pb-2	98.910	99.900	103.800	100.900	2.570	2.550	FS-Pb-2	W26-W	100.90				100.90
W26-F	FS-Pb-2	217.000	214.500	214.800	215.400	1.390	0.640	FS-Pb-2	W26-F	215.40				215.40
W27-M	FS-Pb-2	108.900	105.400	105.600	106.600			FS-Pb-2	W27-M	106.60				106.60

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Cu-1							PACl-Cu-1	W1-W			W1		
W1-F	PACl-Cu-1							PACl-Cu-1	W1-F			W2		
W2-M	PACl-Cu-1							PACl-Cu-1	W2-M			W3		
W2-W	PACl-Cu-1							PACl-Cu-1	W2-W			W4		
W2-F	PACl-Cu-1							PACl-Cu-1	W2-F			W5		
W3-M	PACl-Cu-1							PACl-Cu-1	W3-M			W6		
W3-W	PACl-Cu-1							PACl-Cu-1	W3-W			W7		
W3-F	PACl-Cu-1							PACl-Cu-1	W3-F			W8		
W4-M	PACl-Cu-1							PACl-Cu-1	W4-M			W9		
W4-W	PACl-Cu-1							PACl-Cu-1	W4-W			W10		
W4-F	PACl-Cu-1							PACl-Cu-1	W4-F			W11		
W5-M	PACl-Cu-1							PACl-Cu-1	W5-M			W12		
W5-W	PACl-Cu-1							PACl-Cu-1	W5-W			W13		
W5-F	PACl-Cu-1							PACl-Cu-1	W5-F			W14		
W6-M	PACl-Cu-1							PACl-Cu-1	W6-M			W15		
W6-W	PACl-Cu-1							PACl-Cu-1	W6-W			W16		
W6-F	PACl-Cu-1							PACl-Cu-1	W6-F			W17	14.52	
W7-M	PACl-Cu-1							PACl-Cu-1	W7-M			W18	22.24	
W7-W	PACl-Cu-1							PACl-Cu-1	W7-W			W19	23.29	
W7-F	PACl-Cu-1							PACl-Cu-1	W7-F			W20	25.02	
W8-M	PACl-Cu-1							PACl-Cu-1	W8-M			W21	31.24	
W8-W	PACl-Cu-1							PACl-Cu-1	W8-W			W22	27.03	
W8-F	PACl-Cu-1							PACl-Cu-1	W8-F			W23	18.15	
W9-M	PACl-Cu-1							PACl-Cu-1	W9-M			W24	16.40	
W9-W	PACl-Cu-1							PACl-Cu-1	W9-W			W25	11.26	
W9-F	PACl-Cu-1							PACl-Cu-1	W9-F			W26	8.72	
W10-M	PACl-Cu-1							PACl-Cu-1	W10-M			W27	12.39	
W10-W	PACl-Cu-1							PACl-Cu-1	W10-W					
W10-F	PACl-Cu-1							PACl-Cu-1	W10-F					
W11-M	PACl-Cu-1							PACl-Cu-1	W11-M					
W11-W	PACl-Cu-1							PACl-Cu-1	W11-W					
W11-F	PACl-Cu-1							PACl-Cu-1	W11-F					
W12-M	PACl-Cu-1							PACl-Cu-1	W12-M					
W12-W	PACl-Cu-1							PACl-Cu-1	W12-W					
W12-F	PACl-Cu-1							PACl-Cu-1	W12-F					
W13-M	PACl-Cu-1							PACl-Cu-1	W13-M					
W13-W	PACl-Cu-1							PACl-Cu-1	W13-W					
W13-F	PACl-Cu-1							PACl-Cu-1	W13-F					
W14-M	PACl-Cu-1							PACl-Cu-1	W14-M					
W14-W	PACl-Cu-1							PACl-Cu-1	W14-W					
W14-F	PACl-Cu-1							PACl-Cu-1	W14-F					
W15-M	PACl-Cu-1							PACl-Cu-1	W15-M					
W15-W	PACl-Cu-1							PACl-Cu-1	W15-W					
W15-F	PACl-Cu-1							PACl-Cu-1	W15-F					
W16-M	PACl-Cu-1							PACl-Cu-1	W16-M					
W16-W	PACl-Cu-1							PACl-Cu-1	W16-W					
W16-F	PACl-Cu-1							PACl-Cu-1	W16-F					
W17-M	PACl-Cu-1	23.960	23.250	24.850	24.020	0.801	3.340	PACl-Cu-1	W17-M	24.02	24.69			24.02
W17-W	PACl-Cu-1							PACl-Cu-1	W17-W	0.00	0.00			0.00
W17-F	PACl-Cu-1	29.740	28.940	28.040	28.910	0.848	2.930	PACl-Cu-1	W17-F	28.91	18.87			28.91
W18-M	PACl-Cu-1	36.730	36.750	21.960	31.820	8.534	26.820	PACl-Cu-1	W18-M	31.82	23.06			31.82
W18-W	PACl-Cu-1	34.240	32.170	32.210	32.880	1.184	3.600	PACl-Cu-1	W18-W	32.88	27.55			32.88
W18-F	PACl-Cu-1	23.520	21.970	26.000	23.830	2.031	8.520	PACl-Cu-1	W18-F	23.83	16.13			23.83
W19-M	PACl-Cu-1	42.110	38.930	39.940	40.330	1.625	4.030	PACl-Cu-1	W19-M	40.33	30.76			40.33
W19-W	PACl-Cu-1	36.280	34.660	33.450	34.800	1.420	4.080	PACl-Cu-1	W19-W	34.80	21.67			34.80
W19-F	PACl-Cu-1	28.280	29.330	28.500	28.700	0.556	1.940	PACl-Cu-1	W19-F	28.70	17.44			28.70
W20-M	PACl-Cu-1	43.140	42.620	40.730	42.160	1.269	3.010	PACl-Cu-1	W20-M	42.16	28.77			42.16
W20-W	PACl-Cu-1	39.810	40.060	39.240	39.700	0.418	1.050	PACl-Cu-1	W20-W	39.70	25.47			39.70
W20-F	PACl-Cu-1	32.070	29.960	29.310	30.450	1.441	4.730	PACl-Cu-1	W20-F	30.45	20.82			30.45
W21-M	PACl-Cu-1	42.520	43.280	39.630	41.810	1.925	4.600	PACl-Cu-1	W21-M	41.81	36.48			41.81
W21-W	PACl-Cu-1	41.540	36.550	42.390	40.160	3.155	7.860	PACl-Cu-1	W21-W	40.16	36.18			40.16
W21-F	PACl-Cu-1	27.470	29.090	27.420	27.990	0.950	3.390	PACl-Cu-1	W21-F	27.99	21.05			27.99
W22-M	PACl-Cu-1	34.460	37.520	33.450	35.140	2.118	6.030	PACl-Cu-1	W22-M	35.14	29.15			35.14
W22-W	PACl-Cu-1	32.210	31.520	29.770	31.170	1.257	4.030	PACl-Cu-1	W22-W	31.17	28.01			31.17
W22-F	PACl-Cu-1	32.150	30.960	30.130	31.090	0.999	3.210	PACl-Cu-1	W22-F	31.09	23.94			31.09
W23-M	PACl-Cu-1	20.030	19.390	19.050	19.490	0.499	2.560	PACl-Cu-1	W23-M	19.49	18.73			19.49
W23-W	PACl-Cu-1	22.860	26.940	21.540	23.780	2.812	11.820	PACl-Cu-1	W23-W	23.78	17.70			23.78
W23-F	PACl-Cu-1	12.140	10.060	10.290	10.830	1.141	10.530	PACl-Cu-1	W23-F	10.83	18.02			10.83
W24-M	PACl-Cu-1	26.560	26.210	21.290	24.680	2.946	11.930	PACl-Cu-1	W24-M	24.68	14.41			24.68
W24-W	PACl-Cu-1	33.230	31.870	31.800	32.300	0.804	2.490	PACl-Cu-1	W24-W	32.30	20.87			32.30
W24-F	PACl-Cu-1	24.590	23.030	22.440	23.350	1.113	4.770	PACl-Cu-1	W24-F	23.35	13.93			23.35
W25-M	PACl-Cu-1	30.280	22.210	23.030	25.180	4.443	17.650	PACl-Cu-1	W25-M	25.18	16.01			25.18
W25-W	PACl-Cu-1	21.320	11.250	16.200	16.260	5.033	30.960	PACl-Cu-1	W25-W	16.26	11.20			16.26
W25-F	PACl-Cu-1	10.830	10.690	9.950	10.490	0.473	4.510	PACl-Cu-1	W25-F	10.49	6.57			10.49
W26-M	PACl-Cu-1	8.350	8.089	8.480	8.306	0.200	2.400	PACl-Cu-1	W26-M	8.31	4.15			8.31
W26-W	PACl-Cu-1	11.250	12.610	10.320	11.400	1.153	10.120	PACl-Cu-1	W26-W	11.40	6.22			11.40
W26-F	PACl-Cu-1	23.110	18.590	17.240	19.650	3.072	15.640	PACl-Cu-1	W26-F	19.65	15.78			19.65
W27-M	PACl-Cu-1	13.390	11.640	12.140	12.390			PACl-Cu-1	W27-M	12.39	12.39			12.39

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Cu-2							PACl-Cu-2	W1-W					
W1-F	PACl-Cu-2							PACl-Cu-2	W1-F					
W2-M	PACl-Cu-2							PACl-Cu-2	W2-M					
W2-W	PACl-Cu-2							PACl-Cu-2	W2-W					
W2-F	PACl-Cu-2							PACl-Cu-2	W2-F					
W3-M	PACl-Cu-2							PACl-Cu-2	W3-M					
W3-W	PACl-Cu-2							PACl-Cu-2	W3-W					
W3-F	PACl-Cu-2							PACl-Cu-2	W3-F					
W4-M	PACl-Cu-2							PACl-Cu-2	W4-M					
W4-W	PACl-Cu-2							PACl-Cu-2	W4-W					
W4-F	PACl-Cu-2							PACl-Cu-2	W4-F					
W5-M	PACl-Cu-2							PACl-Cu-2	W5-M					
W5-W	PACl-Cu-2							PACl-Cu-2	W5-W					
W5-F	PACl-Cu-2							PACl-Cu-2	W5-F					
W6-M	PACl-Cu-2							PACl-Cu-2	W6-M					
W6-W	PACl-Cu-2							PACl-Cu-2	W6-W					
W6-F	PACl-Cu-2							PACl-Cu-2	W6-F					
W7-M	PACl-Cu-2							PACl-Cu-2	W7-M					
W7-W	PACl-Cu-2							PACl-Cu-2	W7-W					
W7-F	PACl-Cu-2							PACl-Cu-2	W7-F					
W8-M	PACl-Cu-2							PACl-Cu-2	W8-M					
W8-W	PACl-Cu-2							PACl-Cu-2	W8-W					
W8-F	PACl-Cu-2							PACl-Cu-2	W8-F					
W9-M	PACl-Cu-2							PACl-Cu-2	W9-M					
W9-W	PACl-Cu-2							PACl-Cu-2	W9-W					
W9-F	PACl-Cu-2							PACl-Cu-2	W9-F					
W10-M	PACl-Cu-2							PACl-Cu-2	W10-M					
W10-W	PACl-Cu-2							PACl-Cu-2	W10-W					
W10-F	PACl-Cu-2							PACl-Cu-2	W10-F					
W11-M	PACl-Cu-2							PACl-Cu-2	W11-M					
W11-W	PACl-Cu-2							PACl-Cu-2	W11-W					
W11-F	PACl-Cu-2							PACl-Cu-2	W11-F					
W12-M	PACl-Cu-2							PACl-Cu-2	W12-M					
W12-W	PACl-Cu-2							PACl-Cu-2	W12-W					
W12-F	PACl-Cu-2							PACl-Cu-2	W12-F					
W13-M	PACl-Cu-2							PACl-Cu-2	W13-M					
W13-W	PACl-Cu-2							PACl-Cu-2	W13-W					
W13-F	PACl-Cu-2							PACl-Cu-2	W13-F					
W14-M	PACl-Cu-2							PACl-Cu-2	W14-M					
W14-W	PACl-Cu-2							PACl-Cu-2	W14-W					
W14-F	PACl-Cu-2							PACl-Cu-2	W14-F					
W15-M	PACl-Cu-2							PACl-Cu-2	W15-M					
W15-W	PACl-Cu-2							PACl-Cu-2	W15-W					
W15-F	PACl-Cu-2							PACl-Cu-2	W15-F					
W16-M	PACl-Cu-2							PACl-Cu-2	W16-M					
W16-W	PACl-Cu-2							PACl-Cu-2	W16-W					
W16-F	PACl-Cu-2							PACl-Cu-2	W16-F					
W17-M	PACl-Cu-2	26.670	24.090	25.300	25.350	1.293	5.100	PACl-Cu-2	W17-M	25.35				25.35
W17-W	PACl-Cu-2							PACl-Cu-2	W17-W	0.00				0.00
W17-F	PACl-Cu-2	11.440	4.383	10.640	8.821	3.865	43.810	PACl-Cu-2	W17-F	8.82				8.82
W18-M	PACl-Cu-2	14.590	13.730	14.580	14.300	0.496	3.470	PACl-Cu-2	W18-M	14.30				14.30
W18-W	PACl-Cu-2	20.990	26.590	19.050	22.210	3.917	17.640	PACl-Cu-2	W18-W	22.21				22.21
W18-F	PACl-Cu-2	9.210	9.216	6.850	8.425	1.364	16.190	PACl-Cu-2	W18-F	8.43				8.43
W19-M	PACl-Cu-2	20.700	23.210	19.640	21.180	1.837	8.670	PACl-Cu-2	W19-M	21.18				21.18
W19-W	PACl-Cu-2	9.624	8.043	7.945	8.537	0.942	11.030	PACl-Cu-2	W19-W	8.54				8.54
W19-F	PACl-Cu-2	6.290	5.904	6.328	6.174	0.235	3.800	PACl-Cu-2	W19-F	6.17				6.17
W20-M	PACl-Cu-2	16.480	14.380	15.250	15.370	1.057	6.880	PACl-Cu-2	W20-M	15.37				15.37
W20-W	PACl-Cu-2	10.270	12.210	11.230	11.240	0.972	8.650	PACl-Cu-2	W20-W	11.24				11.24
W20-F	PACl-Cu-2	10.450	13.380	9.701	11.180	1.946	17.410	PACl-Cu-2	W20-F	11.18				11.18
W21-M	PACl-Cu-2	30.930	25.680	36.830	31.150	5.582	17.920	PACl-Cu-2	W21-M	31.15				31.15
W21-W	PACl-Cu-2	32.600	32.440	31.520	32.190	0.586	1.820	PACl-Cu-2	W21-W	32.19				32.19
W21-F	PACl-Cu-2	14.750	13.580	13.990	14.110	0.596	4.230	PACl-Cu-2	W21-F	14.11				14.11
W22-M	PACl-Cu-2	23.200	23.830	22.420	23.150	0.710	3.070	PACl-Cu-2	W22-M	23.15				23.15
W22-W	PACl-Cu-2	25.540	25.340	23.630	24.840	1.051	4.230	PACl-Cu-2	W22-W	24.84				24.84
W22-F	PACl-Cu-2	14.660	18.070	17.630	16.790	1.854	11.040	PACl-Cu-2	W22-F	16.79				16.79
W23-M	PACl-Cu-2	15.710	14.950	23.210	17.960	4.563	25.410	PACl-Cu-2	W23-M	17.96				17.96
W23-W	PACl-Cu-2	11.300	12.940	10.590	11.610	1.203	10.360	PACl-Cu-2	W23-W	11.61				11.61
W23-F	PACl-Cu-2	27.460	23.410	24.740	25.200	2.064	8.160	PACl-Cu-2	W23-F	25.20				25.20
W24-M	PACl-Cu-2	4.768	3.745	3.902	4.138	0.551	13.310	PACl-Cu-2	W24-M	4.14				4.14
W24-W	PACl-Cu-2	9.725	9.168	9.455	9.449	0.279	2.950	PACl-Cu-2	W24-W	9.45				9.45
W24-F	PACl-Cu-2	4.298	3.664	5.567	4.510	0.969	21.490	PACl-Cu-2	W24-F	4.51				4.51
W25-M	PACl-Cu-2	9.551	5.515	5.439	6.835	2.353	34.420	PACl-Cu-2	W25-M	6.84				6.84
W25-W	PACl-Cu-2	8.587	6.222	3.582	6.130	2.504	40.840	PACl-Cu-2	W25-W	6.13				6.13
W25-F	PACl-Cu-2	1.569	3.155	3.227	2.650	0.937	35.370	PACl-Cu-2	W25-F	2.65				2.65
W26-M	PACl-Cu-2	0.048	-0.180	-0.346	-0.159	0.198	123.940	PACl-Cu-2	W26-M	0.00				-0.16
W26-W	PACl-Cu-2	1.109	1.627	0.355	1.030	0.639	62.060	PACl-Cu-2	W26-W	1.03				1.03
W26-F	PACl-Cu-2	12.390	13.050	10.300	11.910	1.437	12.070	PACl-Cu-2	W26-F	11.91				11.91
W27-M	PACl-Cu-2	-	-	-	-	-	-	PACl-Cu-2	W27-M	-				-

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Pb-1							PACl-Pb-1	W1-W			W1		
W1-F	PACl-Pb-1							PACl-Pb-1	W1-F			W2		
W2-M	PACl-Pb-1							PACl-Pb-1	W2-M			W3		
W2-W	PACl-Pb-1							PACl-Pb-1	W2-W			W4		
W2-F	PACl-Pb-1							PACl-Pb-1	W2-F			W5		
W3-M	PACl-Pb-1							PACl-Pb-1	W3-M			W6		
W3-W	PACl-Pb-1							PACl-Pb-1	W3-W			W7		
W3-F	PACl-Pb-1							PACl-Pb-1	W3-F			W8		
W4-M	PACl-Pb-1							PACl-Pb-1	W4-M			W9		
W4-W	PACl-Pb-1							PACl-Pb-1	W4-W			W10		
W4-F	PACl-Pb-1							PACl-Pb-1	W4-F			W11		
W5-M	PACl-Pb-1							PACl-Pb-1	W5-M			W12		
W5-W	PACl-Pb-1							PACl-Pb-1	W5-W			W13		
W5-F	PACl-Pb-1							PACl-Pb-1	W5-F			W14		
W6-M	PACl-Pb-1							PACl-Pb-1	W6-M			W15		
W6-W	PACl-Pb-1							PACl-Pb-1	W6-W			W16		
W6-F	PACl-Pb-1							PACl-Pb-1	W6-F			W17	70.16	
W7-M	PACl-Pb-1							PACl-Pb-1	W7-M			W18	97.32	
W7-W	PACl-Pb-1							PACl-Pb-1	W7-W			W19	98.14	
W7-F	PACl-Pb-1							PACl-Pb-1	W7-F			W20	99.08	
W8-M	PACl-Pb-1							PACl-Pb-1	W8-M			W21	94.89	
W8-W	PACl-Pb-1							PACl-Pb-1	W8-W			W22	112.45	
W8-F	PACl-Pb-1							PACl-Pb-1	W8-F			W23	101.49	
W9-M	PACl-Pb-1							PACl-Pb-1	W9-M			W24	115.11	
W9-W	PACl-Pb-1							PACl-Pb-1	W9-W			W25	81.72	
W9-F	PACl-Pb-1							PACl-Pb-1	W9-F			W26	85.95	
W10-M	PACl-Pb-1							PACl-Pb-1	W10-M			W27	97.96	
W10-W	PACl-Pb-1							PACl-Pb-1	W10-W					
W10-F	PACl-Pb-1							PACl-Pb-1	W10-F					
W11-M	PACl-Pb-1							PACl-Pb-1	W11-M					
W11-W	PACl-Pb-1							PACl-Pb-1	W11-W					
W11-F	PACl-Pb-1							PACl-Pb-1	W11-F					
W12-M	PACl-Pb-1							PACl-Pb-1	W12-M					
W12-W	PACl-Pb-1							PACl-Pb-1	W12-W					
W12-F	PACl-Pb-1							PACl-Pb-1	W12-F					
W13-M	PACl-Pb-1							PACl-Pb-1	W13-M					
W13-W	PACl-Pb-1							PACl-Pb-1	W13-W					
W13-F	PACl-Pb-1							PACl-Pb-1	W13-F					
W14-M	PACl-Pb-1							PACl-Pb-1	W14-M					
W14-W	PACl-Pb-1							PACl-Pb-1	W14-W					
W14-F	PACl-Pb-1							PACl-Pb-1	W14-F					
W15-M	PACl-Pb-1							PACl-Pb-1	W15-M					
W15-W	PACl-Pb-1							PACl-Pb-1	W15-W					
W15-F	PACl-Pb-1							PACl-Pb-1	W15-F					
W16-M	PACl-Pb-1							PACl-Pb-1	W16-M					
W16-W	PACl-Pb-1							PACl-Pb-1	W16-W					
W16-F	PACl-Pb-1							PACl-Pb-1	W16-F					
W17-M	PACl-Pb-1	197.700	129.800	152.700	16.010	34.530	21.570	PACl-Pb-1	W17-M	16.01	69.56			16.01
W17-W	PACl-Pb-1	77.190	78.510	75.040	76.910	7.753	2.280	PACl-Pb-1	W17-W	76.91	73.09			76.91
W17-F	PACl-Pb-1	41.990	40.850	39.310	40.720	1.343	3.300	PACl-Pb-1	W17-F	40.72	67.83			40.72
W18-M	PACl-Pb-1	102.500	102.500	101.500	102.200	0.570	0.560	PACl-Pb-1	W18-M	102.20	95.12			102.20
W18-W	PACl-Pb-1	105.800	106.200	104.600	105.500	0.830	0.790	PACl-Pb-1	W18-W	105.50	99.84			105.50
W18-F	PACl-Pb-1	99.410	106.000	100.400	101.900	3.520	3.460	PACl-Pb-1	W18-F	101.90	97.00			101.90
W19-M	PACl-Pb-1	98.010	102.400	105.300	101.900	3.680	3.610	PACl-Pb-1	W19-M	101.90	97.55			101.90
W19-W	PACl-Pb-1	105.300	105.700	205.900	105.600	0.290	0.280	PACl-Pb-1	W19-W	105.60	102.40			105.60
W19-F	PACl-Pb-1	96.360	96.720	98.090	97.060	0.916	0.940	PACl-Pb-1	W19-F	97.06	94.49			97.06
W20-M	PACl-Pb-1	102.600	103.900	106.100	104.200	1.790	1.720	PACl-Pb-1	W20-M	104.20	101.91			104.20
W20-W	PACl-Pb-1	-	-	-	-	-	-	PACl-Pb-1	W20-W		101.30			-
W20-F	PACl-Pb-1	99.740	100.200	99.550	99.820	0.314	0.310	PACl-Pb-1	W20-F	99.82	94.04			99.82
W21-M	PACl-Pb-1	67.160	69.930	71.760	69.510	2.301	3.310	PACl-Pb-1	W21-M	69.51	70.47			69.51
W21-W	PACl-Pb-1	93.520	91.380	97.260	94.050	2.979	3.170	PACl-Pb-1	W21-W	94.05	95.34			94.05
W21-F	PACl-Pb-1	127.500	129.900	129.500	129.000	1.290	1.000	PACl-Pb-1	W21-F	129.00	118.85			129.00
W22-M	PACl-Pb-1	141.700	145.900	136.500	141.400	4.730	3.340	PACl-Pb-1	W22-M	141.40	124.60			141.40
W22-W	PACl-Pb-1	109.800	108.300	104.100	107.400	2.970	2.760	PACl-Pb-1	W22-W	107.40	108.75			107.40
W22-F	PACl-Pb-1	108.400	103.200	105.800	105.800	2.620	2.480	PACl-Pb-1	W22-F	105.80	104.00			105.80
W23-M	PACl-Pb-1	108.100	101.500	102.100	103.900	3.650	3.520	PACl-Pb-1	W23-M	103.90	99.64			103.90
W23-W	PACl-Pb-1	107.200	96.340	96.680	100.100	6.150	6.150	PACl-Pb-1	W23-W	100.10	99.09			100.10
W23-F	PACl-Pb-1	105.000	108.300	111.600	108.300	3.320	3.070	PACl-Pb-1	W23-F	108.30	105.75			108.30
W24-M	PACl-Pb-1	178.700	179.400	156.800	171.600	12.850	7.490	PACl-Pb-1	W24-M	171.60	140.80			171.60
W24-W	PACl-Pb-1	105.400	106.600	107.600	106.500	1.130	1.060	PACl-Pb-1	W24-W	106.50	102.83			106.50
W24-F	PACl-Pb-1	105.800	101.000	106.900	104.500	3.100	2.970	PACl-Pb-1	W24-F	104.50	101.70			104.50
W25-M	PACl-Pb-1	102.400	95.290	96.320	98.020	3.860	3.940	PACl-Pb-1	W25-M	98.02	98.77			98.02
W25-W	PACl-Pb-1	-	-	-	-	-	-	PACl-Pb-1	W25-W		90.94			-
W25-F	PACl-Pb-1	-	-	-	-	-	-	PACl-Pb-1	W25-F		55.46			-
W26-M	PACl-Pb-1	83.880	80.380	83.800	82.690	1.999	2.420	PACl-Pb-1	W26-M	82.69	79.21			82.69
W26-W	PACl-Pb-1	77.020	79.990	80.530	79.180	1.889	2.390	PACl-Pb-1	W26-W	79.18	75.96			79.18
W26-F	PACl-Pb-1	103.600	106.900	107.800	106.100	2.230	2.100	PACl-Pb-1	W26-F	106.10	102.70			106.10
W27-M	PACl-Pb-1	101.000	104.400	106.100	103.800			PACl-Pb-1	W27-M	103.80	97.96			103.80

		Pb (Dissolved)												
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Sample ID	Week ID	Average Pb (per pipe)	Daily Average (Duplicate Pipe Type)	Week	Weekly Average (Pipe Type)	Average Pb (per pipe)
W1-W	PACl-Pb-2							PACl-Pb-2	W1-W					
W1-F	PACl-Pb-2							PACl-Pb-2	W1-F					
W2-M	PACl-Pb-2							PACl-Pb-2	W2-M					
W2-W	PACl-Pb-2							PACl-Pb-2	W2-W					
W2-F	PACl-Pb-2							PACl-Pb-2	W2-F					
W3-M	PACl-Pb-2							PACl-Pb-2	W3-M					
W3-W	PACl-Pb-2							PACl-Pb-2	W3-W					
W3-F	PACl-Pb-2							PACl-Pb-2	W3-F					
W4-M	PACl-Pb-2							PACl-Pb-2	W4-M					
W4-W	PACl-Pb-2							PACl-Pb-2	W4-W					
W4-F	PACl-Pb-2							PACl-Pb-2	W4-F					
W5-M	PACl-Pb-2							PACl-Pb-2	W5-M					
W5-W	PACl-Pb-2							PACl-Pb-2	W5-W					
W5-F	PACl-Pb-2							PACl-Pb-2	W5-F					
W6-M	PACl-Pb-2							PACl-Pb-2	W6-M					
W6-W	PACl-Pb-2							PACl-Pb-2	W6-W					
W6-F	PACl-Pb-2							PACl-Pb-2	W6-F					
W7-M	PACl-Pb-2							PACl-Pb-2	W7-M					
W7-W	PACl-Pb-2							PACl-Pb-2	W7-W					
W7-F	PACl-Pb-2							PACl-Pb-2	W7-F					
W8-M	PACl-Pb-2							PACl-Pb-2	W8-M					
W8-W	PACl-Pb-2							PACl-Pb-2	W8-W					
W8-F	PACl-Pb-2							PACl-Pb-2	W8-F					
W9-M	PACl-Pb-2							PACl-Pb-2	W9-M					
W9-W	PACl-Pb-2							PACl-Pb-2	W9-W					
W9-F	PACl-Pb-2							PACl-Pb-2	W9-F					
W10-M	PACl-Pb-2							PACl-Pb-2	W10-M					
W10-W	PACl-Pb-2							PACl-Pb-2	W10-W					
W10-F	PACl-Pb-2							PACl-Pb-2	W10-F					
W11-M	PACl-Pb-2							PACl-Pb-2	W11-M					
W11-W	PACl-Pb-2							PACl-Pb-2	W11-W					
W11-F	PACl-Pb-2							PACl-Pb-2	W11-F					
W12-M	PACl-Pb-2							PACl-Pb-2	W12-M					
W12-W	PACl-Pb-2							PACl-Pb-2	W12-W					
W12-F	PACl-Pb-2							PACl-Pb-2	W12-F					
W13-M	PACl-Pb-2							PACl-Pb-2	W13-M					
W13-W	PACl-Pb-2							PACl-Pb-2	W13-W					
W13-F	PACl-Pb-2							PACl-Pb-2	W13-F					
W14-M	PACl-Pb-2							PACl-Pb-2	W14-M					
W14-W	PACl-Pb-2							PACl-Pb-2	W14-W					
W14-F	PACl-Pb-2							PACl-Pb-2	W14-F					
W15-M	PACl-Pb-2							PACl-Pb-2	W15-M					
W15-W	PACl-Pb-2							PACl-Pb-2	W15-W					
W15-F	PACl-Pb-2							PACl-Pb-2	W15-F					
W16-M	PACl-Pb-2							PACl-Pb-2	W16-M					
W16-W	PACl-Pb-2							PACl-Pb-2	W16-W					
W16-F	PACl-Pb-2							PACl-Pb-2	W16-F					
W17-M	PACl-Pb-2	124.400	124.500	120.700	123.100	2.050	1.670	PACl-Pb-2	W17-M	123.10				123.10
W17-W	PACl-Pb-2	71.710	68.210	67.870	69.260	2.124	3.070	PACl-Pb-2	W17-W	69.26				69.26
W17-F	PACl-Pb-2	95.510	95.630	93.680	94.940	1.091	1.150	PACl-Pb-2	W17-F	94.94				94.94
W18-M	PACl-Pb-2	89.220	86.910	87.970	88.030	1.157	1.310	PACl-Pb-2	W18-M	88.03				88.03
W18-W	PACl-Pb-2	95.120	93.470	93.960	94.180	0.848	0.900	PACl-Pb-2	W18-W	94.18				94.18
W18-F	PACl-Pb-2	98.650	89.660	87.970	92.100	5.742	6.240	PACl-Pb-2	W18-F	92.10				92.10
W19-M	PACl-Pb-2	97.640	88.660	93.270	93.190	4.492	4.820	PACl-Pb-2	W19-M	93.19				93.19
W19-W	PACl-Pb-2	98.000	100.200	99.370	99.200	1.117	1.130	PACl-Pb-2	W19-W	99.20				99.20
W19-F	PACl-Pb-2	90.470	92.220	93.050	91.910	1.316	1.430	PACl-Pb-2	W19-F	91.91				91.91
W20-M	PACl-Pb-2	98.070	100.000	100.800	99.620	1.392	1.400	PACl-Pb-2	W20-M	99.62				99.62
W20-W	PACl-Pb-2	105.700	100.300	97.840	101.300	4.010	3.950	PACl-Pb-2	W20-W	101.30				101.30
W20-F	PACl-Pb-2	89.290	88.250	87.290	88.260	0.974	1.100	PACl-Pb-2	W20-F	88.26				88.26
W21-M	PACl-Pb-2	71.850	73.220	69.220	71.430	2.032	2.850	PACl-Pb-2	W21-M	71.43				71.43
W21-W	PACl-Pb-2	105.800	90.590	93.550	96.630	8.047	8.330	PACl-Pb-2	W21-W	96.63				96.63
W21-F	PACl-Pb-2	108.100	108.200	109.800	108.700	0.950	0.870	PACl-Pb-2	W21-F	108.70				108.70
W22-M	PACl-Pb-2	103.300	110.800	109.300	107.800	3.980	3.690	PACl-Pb-2	W22-M	107.80				107.80
W22-W	PACl-Pb-2	109.900	111.300	1058.900	110.100	1.210	1.100	PACl-Pb-2	W22-W	110.10				110.10
W22-F	PACl-Pb-2	102.300	101.400	102.800	102.200	0.750	0.740	PACl-Pb-2	W22-F	102.20				102.20
W23-M	PACl-Pb-2	92.270	92.880	101.000	95.370	4.849	5.080	PACl-Pb-2	W23-M	95.37				95.37
W23-W	PACl-Pb-2	88.260	103.400	102.600	98.080	8.515	8.680	PACl-Pb-2	W23-W	98.08				98.08
W23-F	PACl-Pb-2	102.200	103.800	103.500	103.200	0.860	0.840	PACl-Pb-2	W23-F	103.20				103.20
W24-M	PACl-Pb-2	108.400	109.100	112.400	110.000	2.130	1.930	PACl-Pb-2	W24-M	110.00				110.00
W24-W	PACl-Pb-2	100.600	98.470	98.460	99.160	1.207	1.220	PACl-Pb-2	W24-W	99.16				99.16
W24-F	PACl-Pb-2	101.100	93.670	101.900	98.890	4.547	4.600	PACl-Pb-2	W24-F	98.89				98.89
W25-M	PACl-Pb-2	99.860	99.870	98.830	99.520	0.599	0.600	PACl-Pb-2	W25-M	99.52				99.52
W25-W	PACl-Pb-2	90.200	89.820	92.790	90.940	1.619	1.780	PACl-Pb-2	W25-W	90.94				90.94
W25-F	PACl-Pb-2	56.580	54.560	55.240	55.460	1.027	1.850	PACl-Pb-2	W25-F	55.46				55.46
W26-M	PACl-Pb-2	75.550	75.660	75.990	75.730	0.226	0.300	PACl-Pb-2	W26-M	75.73				75.73
W26-W	PACl-Pb-2	70.790	74.300	73.110	72.730	1.788	2.460	PACl-Pb-2	W26-W	72.73				72.73
W26-F	PACl-Pb-2	97.130	100.100	100.600	99.290	1.890	1.900	PACl-Pb-2	W26-F	99.29				99.29
W27-M	PACl-Pb-2	88.380	93.470	94.480	92.110			PACl-Pb-2	W27-M	92.11				92.11

APPENDIX D – Chapter 7 Raw and Supplemental Data

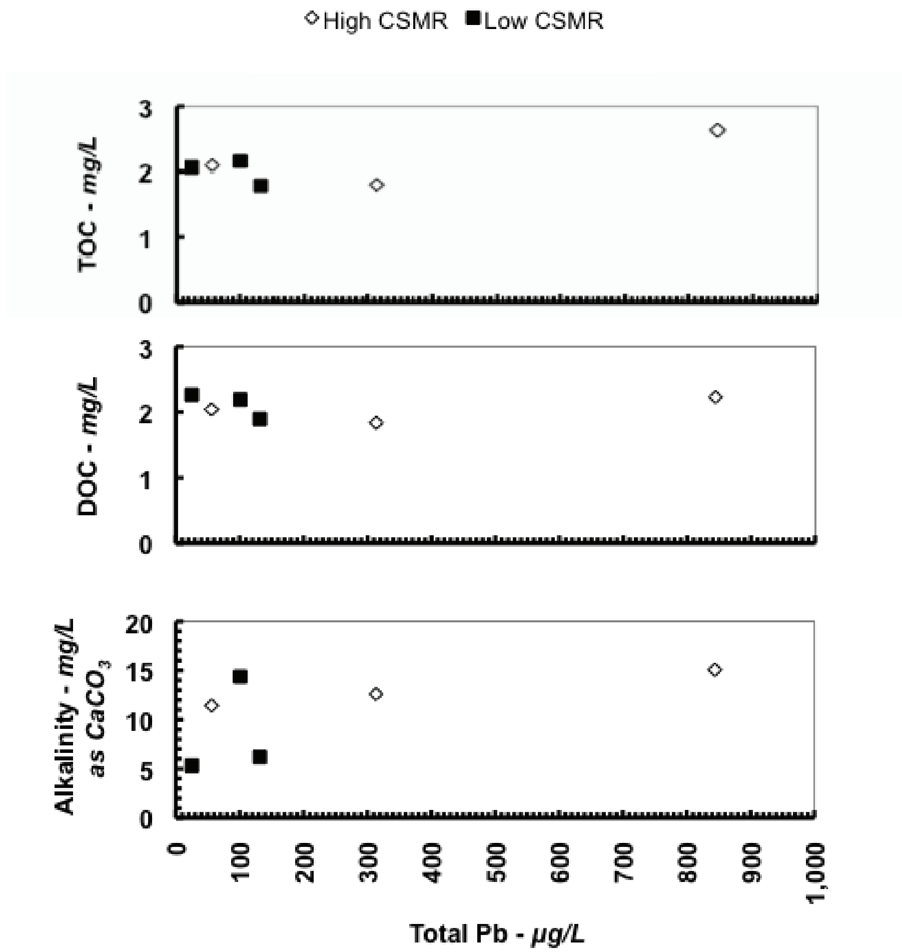


Figure D1. Total organic carbon (TOC), dissolved organic carbon (DOC) and alkalinity plotted against average total lead and copper release for the High CSMR (Weeks 5 through 10) and Low CSMR (Weeks 5 through 14) water conditions tested.

Table D1. High CSMR Total and Dissolved Lead

		Pb (Total)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-T	Alum-1	1498.000	1358.000	1324.000	1393.000	91.900	6.600	1393.000	1590.667	218.944	W1	1590.667	218.944
W2-M	Alum-1	650.700	675.200	718.800	681.600	34.510	5.060	681.600	737.167	77.893	W2	604.467	153.995
W2-T	Alum-1	466.300	446.200	445.200	452.600	11.910	2.630	452.600	471.767	19.776	W3	676.433	258.038
W3-M	Alum-1	221.400	328.400	333.700	294.500	63.340	21.510	294.500	462.100	160.031	W4	343.317	355.834
W3-T	Alum-1	821.300	826.600	864.000	837.300	23.270	2.780	837.300	890.767	55.064	W5	43.680	30.171
W4-M	Alum-1	501.700	541.400	529.700	524.300	20.440	3.900	524.300	656.400	140.493	W6	64.517	7.120
W4-T	Alum-1	0.000	0.000	0.000	0.000	-	-	0.000	30.233	52.366	W7	55.652	8.454
W5-M	Alum-1	18.100	10.230	21.340	16.560	5.713	34.500	16.560	18.900	20.172	W8	52.528	4.060
W5-T	Alum-1	61.790	64.410	61.380	62.530	1.642	2.630	62.530	68.460	5.168	W9	54.428	10.559
W6-M	Alum-1	60.980	59.670	59.700	60.120	0.750	1.250	60.120	65.490	5.109	W10	56.367	2.420
W6-T	Alum-1	52.420	53.760	50.750	52.310	1.508	2.880	52.310	63.543	9.890			
W7-M	Alum-1	38.380	41.320	40.960	40.220	1.605	3.990	40.220	53.687	12.396			
W7-T	Alum-1	53.290	52.950	55.460	53.900	1.360	2.520	53.900	57.617	3.666			
W8-M	Alum-1	49.540	48.000	48.780	48.770	0.767	1.570	48.770	53.553	4.155			
W8-T	Alum-1	46.580	49.320	49.920	48.610	1.783	3.670	48.610	51.503	4.560			
W9-M	Alum-1	73.130	67.890	72.520	71.180	2.868	4.030	71.180	54.117	15.043			
W9-T	Alum-1	51.110	50.460	49.890	50.890	0.608	1.210	50.890	54.740	7.221			
W10-M	Alum-1	54.210	51.560	55.320	53.690	1.933	3.600	53.690	56.367	2.420			
W1-T	Alum-2	1636.000	2072.000	1771.000	1826.000	223.500	12.230	1826.000					
W2-M	Alum-2	723.100	643.700	744.300	703.700	53.030	7.540	703.700					
W2-T	Alum-2	488.200	458.300	465.400	470.600	15.640	3.320	470.600					
W3-M	Alum-2	476.500	485.800	473.300	478.500	6.510	1.360	478.500					
W3-T	Alum-2	914.800	871.200	877.000	887.700	23.680	2.670	887.700					
W4-M	Alum-2	636.600	638.500	647.500	640.900	5.800	0.910	640.900					
W4-T	Alum-2	0.000	0.000	0.000	0.000	-	-	0.000					
W5-M	Alum-2	33.660	35.710	51.060	40.140	9.509	23.690	40.140					
W5-T	Alum-2	72.830	71.720	71.460	72.000	0.730	1.010	72.000					
W6-M	Alum-2	66.010	67.250	64.900	66.060	1.177	1.780	66.060					
W6-T	Alum-2	67.340	65.170	69.630	67.380	2.234	3.320	67.380					
W7-M	Alum-2	56.910	57.050	54.690	56.220	1.323	2.350	56.220					
W7-T	Alum-2	58.230	56.630	58.300	57.720	0.944	1.630	57.720					
W8-M	Alum-2	55.710	54.800	58.280	56.270	1.806	3.210	56.270					
W8-T	Alum-2	50.220	49.640	47.570	49.140	1.391	2.830	49.140					
W9-M	Alum-2	40.810	42.570	44.940	42.770	2.073	4.850	42.770					
W9-T	Alum-2	45.260	50.190	55.330	50.260	5.035	10.020	50.260					
W10-M	Alum-2	55.920	56.440	58.670	57.010	1.458	2.560	57.010					
W1-T	Alum-3	1581.000	1498.000	1581.000	1553.000	47.800	3.080	1553.000					
W2-M	Alum-3	821.100	794.900	861.800	826.200	33.620	4.070	826.200					
W2-T	Alum-3	526.600	445.300	504.500	492.100	42.040	8.540	492.100					
W3-M	Alum-3	645.400	578.500	615.900	613.300	33.540	5.470	613.300					
W3-T	Alum-3	927.000	968.200	946.500	947.300	20.630	2.180	947.300					
W4-M	Alum-3	857.100	838.400	716.400	804.000	76.390	9.500	804.000					
W4-T	Alum-3	99.640	83.610	88.830	90.700	8.173	9.010	90.700					
W5-M	Alum-3	0.000	0.000	0.000	0.000	-	-	0.000					
W5-T	Alum-3	67.170	72.330	73.040	70.850	3.206	4.530	70.850					
W6-M	Alum-3	66.960	74.460	69.440	70.290	3.820	5.430	70.290					
W6-T	Alum-3	73.700	70.100	69.010	70.940	2.454	3.460	70.940					
W7-M	Alum-3	63.080	66.220	64.570	64.620	1.571	2.430	64.620					
W7-T	Alum-3	62.090	60.750	60.890	61.230	0.745	1.220	61.230					
W8-M	Alum-3	54.600	56.050	56.220	55.620	0.890	1.600	55.620					
W8-T	Alum-3	55.630	56.220	58.440	56.760	1.478	2.600	56.760					
W9-M	Alum-3	44.030	48.530	52.360	48.400	4.031	8.330	48.400					
W9-T	Alum-3	64.000	63.800	61.400	63.070	1.447	2.290	63.070					
W10-M	Alum-3	65.200	62.040	47.950	58.400	9.186	15.730	58.400					

		Pb (Total)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-T	FS-1	3219.000	3855.000	3860.000	3645.000	368.400	10.110	3645.000	3600.833	180.841	W1	3600.833	180.841
W2-M	FS-1	1111.000	1042.000	1302.000	1152.000	134.300	11.660	1152.000	1439.000	272.006	W2	1082.067	440.940
W2-T	FS-1	811.200	347.100	421.600	526.600	249.230	47.330	526.600	725.133	172.854	W3	761.183	256.600
W3-M	FS-1	786.800	725.300	752.400	754.800	30.820	4.080	754.800	949.933	170.617	W4	470.400	316.065
W3-T	FS-1	381.500	379.800	402.400	387.900	12.590	3.250	387.900	572.433	169.173	W5	398.983	136.203
W4-M	FS-1	316.800	255.400	306.900	293.000	32.950	11.240	293.000	427.833	185.200	W6	749.683	365.681
W4-T	FS-1	340.200	273.600	257.700	290.500	43.780	15.070	290.500	512.967	458.267	W7	472.567	246.453
W5-M	FS-1	360.500	324.600	343.500	342.900	17.920	5.230	342.900	432.800	172.339	W8	351.483	279.724
W5-T	FS-1	316.600	313.400	331.600	320.500	9.700	3.030	320.500	365.167	115.095	W9	1926.333	754.039
W6-M	FS-1	714.300	715.700	728.700	719.600	7.940	1.100	719.600	935.000	451.625	W10	1487.667	377.852
W6-T	FS-1	521.300	469.700	494.300	495.100	25.800	5.210	495.100	564.367	165.271			
W7-M	FS-1	515.900	509.200	509.900	511.600	3.680	0.720	511.600	632.933	113.612			
W7-T	FS-1	185.400	188.300	186.400	186.700	1.470	0.790	186.700	312.200	248.570			
W8-M	FS-1	195.800	190.900	183.800	190.200	6.010	3.160	190.200	350.467	296.405			
W8-T	FS-1	185.900	181.300	180.100	182.400	3.040	1.660	182.400	352.500	328.260			
W9-M	FS-1	1624.000	1649.000	1605.000	1626.000	22.200	1.370	1626.000	2372.333	863.433			
W9-T	FS-1	1208.000	1166.000	1186.000	1187.000	20.090	1.760	1187.000	1480.333	281.379			
W10-M	FS-1	1168.000	1190.000	1109.000	1156.000	41.900	3.630	1156.000	1487.667	377.852			
W1-T	FS-2	3768.000	3743.000	2909.000	3755.500	12.158	486.300	3755.500					
W2-M	FS-2	1401.000	1510.000	1503.000	1472.000	60.800	4.130	1472.000					
W2-T	FS-2	657.400	850.700	911.800	806.600	132.800	16.460	806.600					
W3-M	FS-2	1031.000	1037.000	1003.000	1024.000	17.900	1.740	1024.000					
W3-T	FS-2	707.300	722.600	730.800	720.200	11.900	1.650	720.200					
W4-M	FS-2	368.900	352.100	333.400	351.500	17.800	5.070	351.500					
W4-T	FS-2	194.400	217.500	213.400	208.400	12.330	5.920	208.400					
W5-M	FS-2	343.500	308.800	319.700	324.000	17.730	5.470	324.000					
W5-T	FS-2	292.900	280.000	264.300	279.100	14.330	5.150	279.100					
W6-M	FS-2	631.900	638.200	624.200	631.400	7.020	1.110	631.400					
W6-T	FS-2	444.900	476.500	413.500	445.000	31.500	7.080	445.000					
W7-M	FS-2	646.900	656.800	647.500	650.400	5.530	0.850	650.400					
W7-T	FS-2	160.000	151.300	142.800	151.400	8.600	5.680	151.400					
W8-M	FS-2	171.400	170.300	164.500	168.700	3.710	2.200	168.700					
W8-T	FS-2	146.400	143.500	142.800	144.200	1.890	1.310	144.200					
W9-M	FS-2	2177.000	2185.000	2156.000	2173.000	14.800	0.680	2173.000					
W9-T	FS-2	1536.000	1439.000	1542.000	1506.000	57.700	3.830	1506.000					
W10-M	FS-2	1379.000	1417.000	1427.000	1408.000	25.100	1.780	1408.000					
W1-T	FS-3	3721.000	2808.000	3677.000	3402.000	515.300	15.150	3402.000					
W2-M	FS-3	1606.000	1940.000	1532.000	1693.000	217.400	12.850	1693.000					
W2-T	FS-3	857.500	829.400	839.700	842.200	14.230	1.690	842.200					
W3-M	FS-3	1059.000	1068.000	1086.000	1071.000	13.800	1.290	1071.000					
W3-T	FS-3	602.900	621.100	603.700	609.200	10.270	1.690	609.200					
W4-M	FS-3	602.100	675.600	639.300	639.000	36.710	5.750	639.000					
W4-T	FS-3	1010.000	1037.000	1072.000	1040.000	31.500	3.030	1040.000					
W5-M	FS-3	694.200	600.000	600.300	631.500	54.270	8.590	631.500					
W5-T	FS-3	501.800	476.800	509.200	495.900	16.980	3.420	495.900					
W6-M	FS-3	1507.000	1390.000	1464.000	1454.000	59.300	4.080	1454.000					
W6-T	FS-3	775.900	722.600	760.400	753.000	27.410	3.640	753.000					
W7-M	FS-3	742.000	759.800	708.500	736.800	26.010	3.530	736.800					
W7-T	FS-3	599.500	594.900	601.100	598.500	3.220	0.540	598.500					
W8-M	FS-3	678.900	689.300	709.400	692.500	15.500	2.240	692.500					
W8-T	FS-3	716.900	744.400	731.300	730.900	13.740	1.880	730.900					
W9-M	FS-3	3316.000	3199.000	3439.000	3318.000	120.000	3.620	3318.000					
W9-T	FS-3	1714.000	1786.000	1745.000	1748.000	36.300	2.080	1748.000					
W10-M	FS-3	1925.000	1910.000	1864.000	1899.000	31.700	1.670	1899.000					

Week ID	Sample ID	Pb (Total) 1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-T	PACl-1	1285.000	1298.000	1220.000	1268.000	41.800	3.290	1268.000	1284.733	344.205	W1	1284.733	344.205
W2-M	PACl-1	752.700	671.300	777.700	733.900	55.650	7.580	733.900	1040.300	265.486	W2	937.833	218.570
W2-T	PACl-1	692.900	670.800	689.100	684.300	11.840	1.730	684.300	835.367	132.101	W3	1143.733	447.947
W3-M	PACl-1	644.000	608.400	585.400	612.200	29.520	4.820	612.200	802.800	225.680	W4	902.950	554.688
W3-T	PACl-1	1363.000	1412.000	1367.000	1381.000	26.900	1.950	1381.000	1484.667	319.378	W5	263.367	109.627
W4-M	PACl-1	1212.000	1237.000	1219.000	1223.000	12.900	1.050	1223.000	1326.333	210.020	W6	160.900	90.096
W4-T	PACl-1	163.900	150.800	165.000	159.900	7.890	4.930	159.900	479.567	432.816	W7	159.483	20.616
W5-M	PACl-1	173.300	178.800	157.700	169.900	10.940	6.440	169.900	305.400	119.220	W8	524.950	114.206
W5-T	PACl-1	133.400	179.200	136.500	149.700	25.610	17.100	149.700	221.333	102.623	W9	396.233	87.785
W6-M	PACl-1	0.000	0.000	0.000	0.000			0.000	152.833	140.640	W10	442.100	40.752
W6-T	PACl-1	172.300	153.700	154.500	160.200	10.540	6.580	160.200	168.967	17.846			
W7-M	PACl-1	143.100	146.900	105.100	131.700	23.080	17.530	131.700	153.133	24.935			
W7-T	PACl-1	123.400	158.600	157.200	146.400	19.890	13.590	146.400	165.833	17.884			
W8-M	PACl-1	593.700	589.900	563.100	582.200	16.680	2.860	582.200	583.900	4.782			
W8-T	PACl-1	291.300	303.100	301.400	298.600	6.370	2.130	298.600	466.000	148.861			
W9-M	PACl-1	297.200	300.000	296.600	297.900	1.820	0.610	297.900	371.967	128.374			
W9-T	PACl-1	408.100	425.800	423.400	419.100	9.600	2.290	419.100	420.500	31.923			
W10-M	PACl-1	437.800	428.000	433.600	433.100	4.910	1.130	433.100	442.100	40.752			
W1-T	PACl-2	1747.000	1442.000	1721.000	1637.000	169.400	10.350	1637.000					
W2-M	PACl-2	1262.000	1198.000	1146.000	1202.000	57.900	4.820	1202.000					
W2-T	PACl-2	873.400	890.500	914.000	892.600	20.400	2.290	892.600					
W3-M	PACl-2	736.200	717.000	779.300	744.200	31.870	4.280	744.200					
W3-T	PACl-2	1840.000	1836.000	1853.000	1843.000	8.700	0.470	1843.000					
W4-M	PACl-2	1585.000	1579.000	1542.000	1568.000	23.300	1.490	1568.000					
W4-T	PACl-2	280.000	323.900	316.100	306.700	23.450	7.650	306.700					
W5-M	PACl-2	345.100	338.600	372.600	352.100	18.030	5.120	352.100					
W5-T	PACl-2	309.800	390.900	315.900	338.900	45.160	13.330	338.900					
W6-M	PACl-2	279.200	278.400	272.800	276.800	3.500	1.270	276.800					
W6-T	PACl-2	186.700	196.400	185.200	189.500	6.070	3.200	189.500					
W7-M	PACl-2	176.500	176.000	189.000	180.500	7.350	4.070	180.500					
W7-T	PACl-2	171.300	190.200	183.300	181.600	9.590	5.280	181.600					
W8-M	PACl-2	550.400	590.100	600.100	580.200	26.300	4.530	580.200					
W8-T	PACl-2	528.700	489.600	529.200	515.900	22.750	4.410	515.900					
W9-M	PACl-2	510.200	519.900	530.600	520.200	10.230	1.970	520.200					
W9-T	PACl-2	415.500	470.100	473.800	453.100	32.650	7.210	453.100					
W10-M	PACl-2	475.800	490.500	493.400	486.600	9.460	1.940	486.600					
W1-T	PACl-3	960.400	989.100	898.300	949.200	46.400	4.890	949.200					
W2-M	PACl-3	1110.000	1080.000	1366.000	1185.000	156.700	13.220	1185.000					
W2-T	PACl-3	925.900	920.400	941.200	929.200	10.780	1.160	929.200					
W3-M	PACl-3	1049.000	1060.000	1046.000	1052.000	7.400	0.700	1052.000					
W3-T	PACl-3	1233.000	1206.000	1250.000	1230.000	22.100	1.790	1230.000					
W4-M	PACl-3	1189.000	1215.000	1160.000	1188.000	27.700	2.330	1188.000					
W4-T	PACl-3	959.400	971.000	986.000	972.100	13.360	1.370	972.100					
W5-M	PACl-3	392.900	393.500	396.300	394.200	1.810	0.460	394.200					
W5-T	PACl-3	195.900	185.100	145.100	175.400	26.750	15.250	175.400					
W6-M	PACl-3	188.100	174.100	182.800	181.700	7.080	3.900	181.700					
W6-T	PACl-3	157.000	160.100	154.500	157.200	2.800	1.780	157.200					
W7-M	PACl-3	159.700	152.100	129.900	147.200	15.480	10.520	147.200					
W7-T	PACl-3	173.900	164.500	170.200	169.500	4.720	2.790	169.500					
W8-M	PACl-3	584.500	589.200	594.000	589.300	4.770	0.810	589.300					
W8-T	PACl-3	596.600	574.600	579.300	583.500	11.580	1.980	583.500					
W9-M	PACl-3	291.400	302.500	299.500	297.800	5.710	1.920	297.800					
W9-T	PACl-3	391.100	391.100	385.900	389.300	2.990	0.770	389.300					
W10-M	PACl-3	399.700	414.300	405.900	406.600	7.320	1.800	406.600					

Week ID	Sample ID	Pb (Dissolved) 1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-T	Alum-1	947.500	985.000	955.800	962.800	19.710	2.050	962.800	1155.600	212.845	W1	1155.600	212.845
W2-M	Alum-1	339.400	340.400	314.300	331.300	14.800	4.470	331.300	591.600	430.917	W2	448.450	314.917
W2-T	Alum-1	268.600	283.100	277.900	276.500	7.370	2.660	276.500	305.300	27.678	W3	140.705	81.672
W3-M	Alum-1	226.800	207.800	209.600	214.800	10.510	4.890	214.800	214.700	13.450	W4	52.172	33.059
W3-T	Alum-1	70.870	69.890	66.530	69.100	2.274	3.290	69.100	66.710	8.317	W5	33.073	2.722
W4-M	Alum-1	41.590	45.680	44.730	44.000	2.139	4.860	44.000	71.570	39.882	W6	25.773	3.012
W4-T	Alum-1	32.890	37.250	36.630	35.590	2.358	6.620	35.590	32.773	3.576	W7	26.150	3.254
W5-M	Alum-1	29.600	30.590	29.060	29.750	0.775	2.600	29.750	31.450	2.639	W8	21.887	3.308
W5-T	Alum-1	33.370	33.890	37.180	34.810	2.069	5.940	34.810	34.697	1.913	W9	26.387	2.420
W6-M	Alum-1	24.320	24.880	23.390	24.200	0.750	3.100	24.200	27.377	3.837	W10	27.030	3.584
W6-T	Alum-1	23.630	22.570	25.380	23.850	1.423	5.970	23.850	24.170	0.487			
W7-M	Alum-1	30.840	29.620	28.960	29.810	0.954	3.200	29.810	28.813	1.590			
W7-T	Alum-1	24.430	24.490	24.430	24.450	0.032	0.130	24.450	23.487	1.634			
W8-M	Alum-1	20.630	20.030	19.660	20.110	0.492	2.440	20.110	19.070	1.295			
W8-T	Alum-1	24.810	23.790	24.870	24.490	0.605	2.470	24.490	24.703	1.372			
W9-M	Alum-1	26.530	26.380	26.490	26.470	0.080	0.300	26.470	25.713	2.406			
W9-T	Alum-1	30.030	30.630	27.720	29.460	1.534	5.210	29.460	27.060	2.736			
W10-M	Alum-1	32.530	29.260	28.750	30.180	2.050	6.790	30.180	27.030	3.584			
W1-T	Alum-2	1422.000	1286.000	1443.000	1384.000	85.000	6.140	1384.000					
W2-M	Alum-2	353.400	344.900	365.100	354.500	10.150	2.860	354.500					
W2-T	Alum-2	297.300	307.700	318.000	307.700	10.320	3.350	307.700					
W3-M	Alum-2	225.000	225.700	233.500	228.100	4.720	2.070	228.100					
W3-T	Alum-2	57.680	56.770	57.930	57.460	0.610	1.060	57.460					
W4-M	Alum-2	55.910	50.910	53.420	53.410	2.503	4.690	53.410					
W4-T	Alum-2	33.910	31.270	36.750	33.980	2.743	8.070	33.980					
W5-M	Alum-2	32.520	35.320	35.650	34.490	1.721	4.990	34.490					
W5-T	Alum-2	31.240	32.590	34.350	32.730	1.558	4.760	32.730					
W6-M	Alum-2	35.400	29.230	30.290	31.640	3.300	10.430	31.640					
W6-T	Alum-2	22.750	24.310	24.740	23.930	1.045	4.360	23.930					
W7-M	Alum-2	27.690	24.960	28.290	26.980	1.775	6.580	26.980					
W7-T	Alum-2	19.790	21.460	23.540	21.600	1.878	8.700	21.600					
W8-M	Alum-2	17.730	17.450	17.670	17.620	0.146	0.830	17.620					
W8-T	Alum-2	23.340	23.220	23.780	23.450	0.295	1.260	23.450					
W9-M	Alum-2	22.220	22.950	23.880	23.020	0.831	3.610	23.020					
W9-T	Alum-2	18.150	31.260	22.830	24.080	6.644	27.590	24.080					
W10-M	Alum-2	24.010	23.510	21.880	23.130	1.115	4.820	23.130					
W1-T	Alum-3	1056.000	1208.000	1095.000	1120.000	78.900	7.040	1120.000					
W2-M	Alum-3	1115.000	1121.000	1033.000	1089.000	49.400	4.530	1089.000					
W2-T	Alum-3	330.600	332.100	332.400	331.700	0.980	0.300	331.700					
W3-M	Alum-3	200.400	203.400	200.000	201.200	1.900	0.940	201.200					
W3-T	Alum-3	72.300	71.990	76.420	73.570	2.472	3.360	73.570					
W4-M	Alum-3	111.600	122.100	118.200	117.300	5.300	4.520	117.300					
W4-T	Alum-3	31.580	28.720	25.960	28.750	2.808	9.770	28.750					
W5-M	Alum-3	31.780	31.960	26.580	30.110	3.053	10.140	30.110					
W5-T	Alum-3	37.430	33.450	38.670	36.550	2.746	7.510	36.550					
W6-M	Alum-3	26.140	26.970	25.760	26.290	0.620	2.360	26.290					
W6-T	Alum-3	24.230	24.190	25.780	24.730	0.907	3.670	24.730					
W7-M	Alum-3	29.350	33.110	26.490	29.650	3.320	11.200	29.650					
W7-T	Alum-3	24.810	24.330	24.080	24.410	0.371	1.520	24.410					
W8-M	Alum-3	19.010	19.670	19.750	19.480	0.405	2.080	19.480					
W8-T	Alum-3	25.870	26.860	25.780	26.170	0.601	2.300	26.170					
W9-M	Alum-3	27.500	27.320	28.140	27.650	0.427	1.550	27.650					
W9-T	Alum-3	25.620	31.020	26.320	27.640	2.934	10.610	27.640					
W10-M	Alum-3	22.360	30.230	30.740	27.780	4.699	16.920	27.780					

		Pb (Dissolved)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-T	FS-1	942.200	916.600	818.700	892.500	65.180	7.300	892.500	1069.600	297.442	W1	1069.600	297.442
W2-M	FS-1	241.600	243.700	221.400	235.500	12.310	5.230	235.500	396.533	244.519	W2	249.990	235.548
W2-T	FS-1	4.096	5.331	6.660	5.362	1.283	23.920	5.362	103.447	120.388	W3	337.483	395.148
W3-M	FS-1	355.500	373.100	372.400	367.000	9.970	2.720	367.000	589.800	434.045	W4	14.780	23.306
W3-T	FS-1	0.000	0.000	0.000	0.000	-	-	0.000	85.167	104.728	W5	49.122	76.780
W4-M	FS-1	54.220	51.880	47.540	51.210	3.393	6.630	51.210	17.070	29.566	W6	240.882	120.262
W4-T	FS-1	42.700	33.750	35.960	37.470	4.660	12.430	37.470	12.490	21.633	W7	141.278	165.335
W5-M	FS-1	0.000	0.000	0.000	0.000	-	-	0.000	0.000	0.000	W8	28.321	36.353
W5-T	FS-1	89.920	92.740	93.960	92.210	2.072	2.250	92.210	98.243	86.598	W9	441.917	182.059
W6-M	FS-1	38.350	42.020	37.790	39.390	2.300	5.840	39.390	205.497	172.198	W10	222.267	126.826
W6-T	FS-1	286.800	262.900	248.800	266.200	19.200	7.210	266.200	276.267	52.430			
W7-M	FS-1	263.400	232.800	282.900	259.700	25.290	9.740	259.700	223.623	193.849			
W7-T	FS-1	0.000	0.000	0.000	0.000	-	-	0.000	58.933	102.076			
W8-M	FS-1	7.011	6.059	6.828	6.633	0.505	7.620	6.633	28.674	44.046			
W8-T	FS-1	13.920	13.980	14.340	14.080	0.226	1.600	14.080	27.967	36.923			
W9-M	FS-1	341.700	330.200	343.100	338.300	7.110	2.100	338.300	515.300	239.715			
W9-T	FS-1	344.200	343.200	278.600	322.000	37.590	11.680	322.000	368.533	96.153			
W10-M	FS-1	124.600	127.900	126.900	126.500	1.690	1.340	126.500	222.267	126.826			
W1-T	FS-2	959.100	833.900	916.700	903.300	63.670	7.050	903.300					
W2-M	FS-2	294.300	279.500	254.900	276.200	19.890	7.200	276.200					
W2-T	FS-2	66.940	66.300	68.300	67.180	1.023	1.520	67.180					
W3-M	FS-2	314.400	315.800	307.000	312.400	4.730	1.510	312.400					
W3-T	FS-2	56.340	54.850	49.000	53.400	3.876	7.260	53.400					
W4-M	FS-2	0.000	0.000	0.000	0.000	-	-	0.000					
W4-T	FS-2	0.000	0.000	0.000	0.000	-	-	0.000					
W5-M	FS-2	0.000	0.000	0.000	0.000	-	-	0.000					
W5-T	FS-2	14.670	15.530	14.250	14.820	0.652	4.400	14.820					
W6-M	FS-2	185.400	199.100	197.100	193.900	7.420	3.830	193.900					
W6-T	FS-2	224.200	232.500	232.100	229.600	4.680	2.040	229.600					
W7-M	FS-2	11.710	7.935	23.170	14.270	7.933	55.590	14.270					
W7-T	FS-2	0.000	0.000	0.000	0.000	-	-	0.000					
W8-M	FS-2	0.000	0.000	0.000	0.000	-	-	0.000					
W8-T	FS-2	0.000	0.000	0.000	0.000	-	-	0.000					
W9-M	FS-2	399.200	438.100	421.300	419.500	19.510	4.650	419.500					
W9-T	FS-2	298.400	304.600	310.600	304.500	6.100	2.000	304.500					
W10-M	FS-2	200.700	133.400	188.400	174.200	35.810	20.560	174.200					
W1-T	FS-3	1423.000	1346.000	1469.000	1413.000	62.600	4.430	1413.000					
W2-M	FS-3	649.100	666.400	718.300	677.900	36.010	5.310	677.900					
W2-T	FS-3	229.200	240.800	243.400	237.800	7.560	3.180	237.800					
W3-M	FS-3	1161.000	1083.000	1025.000	1090.000	68.500	6.290	1090.000					
W3-T	FS-3	194.300	217.100	194.800	202.100	13.020	6.440	202.100					
W4-M	FS-3	0.000	0.000	0.000	0.000	-	-	0.000					
W4-T	FS-3	0.000	0.000	0.000	0.000	-	-	0.000					
W5-M	FS-3	0.000	0.000	0.000	0.000	-	-	0.000					
W5-T	FS-3	190.800	189.200	183.100	187.700	4.070	2.170	187.700					
W6-M	FS-3	375.900	383.500	391.100	383.200	7.600	1.980	383.200					
W6-T	FS-3	329.800	358.300	310.800	333.000	23.950	7.190	333.000					
W7-M	FS-3	405.100	387.900	397.900	396.900	8.620	2.170	396.900					
W7-T	FS-3	175.500	177.100	177.900	176.800	1.230	0.690	176.800					
W8-M	FS-3	79.570	80.280	78.320	79.390	0.993	1.250	79.390					
W8-T	FS-3	70.130	69.690	69.630	69.820	0.274	0.390	69.820					
W9-M	FS-3	749.900	813.800	800.400	788.100	33.700	4.280	788.100					
W9-T	FS-3	598.600	412.700	425.900	479.100	103.740	21.650	479.100					
W10-M	FS-3	371.500	361.200	365.700	366.100	5.200	1.420	366.100					

Week ID	Sample ID	Pb (Dissolved) 1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-T	PACl-1	744.300	664.700	694.200	701.100	40.250	5.740	701.100	681.067	221.331	W1	681.067	221.331
W2-M	PACl-1	551.300	538.700	532.200	540.700	9.710	1.800	540.700	517.233	173.494	W2	428.700	147.086
W2-T	PACl-1	332.400	323.200	299.100	318.300	17.210	5.410	318.300	340.167	21.702	W3	275.800	88.797
W3-M	PACl-1	262.100	327.000	328.900	306.000	37.990	12.420	306.000	336.600	27.149	W4	172.600	71.004
W3-T	PACl-1	308.100	306.800	310.800	308.500	2.030	0.660	308.500	215.000	88.799	W5	143.445	44.320
W4-M	PACl-1	166.200	172.500	177.100	171.900	5.480	3.190	171.900	205.867	80.888	W6	111.405	34.448
W4-T	PACl-1	113.600	116.300	109.900	113.300	3.230	2.850	113.300	139.333	52.353	W7	59.243	26.720
W5-M	PACl-1	138.300	150.000	137.500	141.900	6.980	4.920	141.900	160.033	58.642	W8	291.317	92.634
W5-T	PACl-1	101.400	96.060	97.020	98.170	2.856	2.910	98.170	126.857	25.423	W9	207.750	27.386
W6-M	PACl-1	93.690	88.740	86.830	89.750	3.542	3.950	89.750	104.833	29.477	W10	255.567	26.706
W6-T	PACl-1	168.100	164.700	172.500	168.400	3.880	2.310	168.400	117.977	44.365			
W7-M	PACl-1	77.590	80.730	58.750	72.360	11.891	16.430	72.360	81.977	10.157			
W7-T	PACl-1	24.800	24.010	24.500	24.430	0.399	1.630	24.430	36.510	11.457			
W8-M	PACl-1	343.900	380.100	373.700	365.900	19.320	5.280	365.900	320.600	85.573			
W8-T	PACl-1	185.500	191.200	188.700	188.400	2.850	1.510	188.400	262.033	107.505			
W9-M	PACl-1	185.500	191.200	188.700	188.400	2.850	1.510	188.400	192.767	5.689			
W9-T	PACl-1	215.300	207.500	214.400	212.400	1.498	2.020	212.400	222.733	34.192			
W10-M	PACl-1	243.200	241.800	234.100	239.700	4.920	2.050	239.700	255.567	26.706			
W1-T	PACl-2	1127.000	772.300	775.500	891.700	204.020	22.880	891.700					
W2-M	PACl-2	328.300	324.200	347.100	333.200	12.210	3.660	333.200					
W2-T	PACl-2	353.100	369.100	362.800	361.700	8.050	2.230	361.700					
W3-M	PACl-2	368.000	353.100	352.200	357.800	8.870	2.480	357.800					
W3-T	PACl-2	211.700	200.800	201.600	204.700	6.110	2.980	204.700					
W4-M	PACl-2	304.500	335.600	254.400	298.200	40.970	13.740	298.200					
W4-T	PACl-2	214.700	189.400	194.800	199.600	13.330	6.680	199.600					
W5-M	PACl-2	229.000	229.800	217.900	225.600	6.660	2.950	225.600					
W5-T	PACl-2	155.200	143.600	140.900	146.600	7.630	5.210	146.600					
W6-M	PACl-2	132.500	145.500	138.300	138.800	6.490	4.670	138.800					
W6-T	PACl-2	93.080	112.300	96.340	100.600	10.260	10.210	100.600					
W7-M	PACl-2	93.740	87.400	96.670	92.600	4.737	5.120	92.600					
W7-T	PACl-2	45.120	50.150	46.380	47.220	2.620	5.550	47.220					
W8-M	PACl-2	378.300	366.900	379.200	374.000	6.880	1.840	374.000					
W8-T	PACl-2	407.500	383.200	365.300	385.400	21.200	5.500	385.400					
W9-M	PACl-2	209.500	197.400	190.600	199.200	9.570	4.800	199.200					
W9-T	PACl-2	260.100	255.400	267.000	260.900	5.830	2.230	260.900					
W10-M	PACl-2	290.900	288.100	280.200	286.400	5.500	1.920	286.400					
W1-T	PACl-3	466.400	414.300	470.600	450.400	31.340	6.960	450.400					
W2-M	PACl-3	675.500	678.200	679.500	677.800	2.030	0.300	677.800					
W2-T	PACl-3	343.100	337.300	341.200	340.500	2.940	0.860	340.500					
W3-M	PACl-3	357.800	345.800	334.500	346.000	11.670	3.370	346.000					
W3-T	PACl-3	128.900	136.200	130.800	131.800	3.880	2.940	131.800					
W4-M	PACl-3	151.000	146.900	144.500	147.500	3.250	2.200	147.500					
W4-T	PACl-3	105.700	100.200	109.200	105.100	4.550	4.330	105.100					
W5-M	PACl-3	117.600	109.100	111.100	112.600	4.440	3.950	112.600					
W5-T	PACl-3	149.600	118.700	139.200	135.800	15.760	11.600	135.800					
W6-M	PACl-3	88.970	83.080	85.800	85.950	2.946	3.430	85.950					
W6-T	PACl-3	70.550	93.110	91.110	84.930	12.488	14.700	84.930					
W7-M	PACl-3	65.890	88.610	88.400	80.970	13.057	16.130	80.970					
W7-T	PACl-3	37.130	39.930	36.560	37.880	1.806	4.770	37.880					
W8-M	PACl-3	218.300	222.700	224.600	221.900	3.230	1.460	221.900					
W8-T	PACl-3	213.400	211.800	211.700	212.300	0.950	0.450	212.300					
W9-M	PACl-3	184.300	200.400	187.500	190.700	8.510	4.460	190.700					
W9-T	PACl-3	213.300	207.800	163.600	194.900	27.250	13.980	194.900					
W10-M	PACl-3	239.900	239.000	243.000	240.600	2.090	0.870	240.600					

Table D2. Low CSMR Total and Dissolved Lead

		Pb (Total)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-F	Alum-1	87.020	94.230	99.750	93.670	6.382	6.810	93.670	95.463	3.729	W1	95.463	3.729
W2-T	Alum-1	64.87	59.56	68.4	64.28	4.447	6.92	64.28	64.19	1.10	W2	57.49	7.76
W2-F	Alum-1	52.850	53.720	52.430	53.000	0.657	1.240	53.000	50.783	3.796	W3	37.935	5.241
W3-T	Alum-1	40.64	41.98	46.09	42.9	2.843	6.63	42.9	41.32	1.70	W4	37.28	6.62
W3-F	Alum-1	41.970	33.060	38.580	37.870	4.497	11.870	37.870	34.550	5.604	W5	34.313	11.608
W4-T	Alum-1	35.13	33.1	37.9	35.38	2.412	6.82	35.38	32.08	4.74	W6	16.50	8.42
W4-F	Alum-1	46.340	42.450	46.970	45.260	2.452	5.420	45.260	42.480	2.481	W7	14.152	7.131
W5-T	Alum-1	42.6	43.92	43.62	43.38	0.69	1.59	43.38	42.90	9.26	W8	27.23	5.37
W5-F	Alum-1	31.950	32.130	31.880	31.990	0.125	0.390	31.990	25.727	5.474	W9	26.813	6.701
W6-T	Alum-1									#DIV/0!	W10	35.67	6.96
W6-F	Alum-1	26.360	25.480	26.260	26.030	0.478	1.840	26.030	16.500	8.421	W11	11.285	2.658
W7-T	Alum-1	17.81	16.74	15.9	16.82	0.959	5.7	16.82	10.53	5.45	W12	17.54	2.66
W7-F	Alum-1	30.540	23.430	26.150	26.550	3.328	12.540	26.550	17.770	7.626	W13	17.940	1.130
W8-T	Alum-1	26.65	19.66	28.64	24.65	4.572	18.55	24.65	23.78	3.65	W14	11.08	1.75
W8-F	Alum-1	36.140	36.480	36.100	36.240	0.208	0.580	36.240	30.670	4.824			
W9-T	Alum-1	37.93	37.17	35.92	37.01	1.012	2.73	37.01	30.44	5.73	W14	14.00	4.83
W9-F	Alum-1	29.920	31.440	29.480	30.280	1.029	3.400	30.280	23.190	6.329	W15	24.170	3.047
W10-T	Alum-1	38.95	34.77	37.52	37.08	2.125	5.73	37.08	29.20	6.96	W16	27.57	3.35
W10-F	Alum-1	25.690	25.610	27.880	26.400	1.286	4.872	26.400	42.130	33.035	W17	17.173	6.670
W11-T	Alum-1	13.84	14.36	9.515	12.57	2.661	21.1616	12.57	7.42	5.65	W18	20.78	2.28
W11-F	Alum-1	18.610	18.330	17.520	18.150	0.565	3.114	18.150	15.150	2.658	W19	14.277	1.649
W12-T	Alum-1	21.7	23.72	19.29	21.57	2.22	10.2896	21.57	16.21	4.73			
W12-F	Alum-1	22.470	22.130	22.850	22.490	0.360	1.603	22.490	18.870	3.343			
W13-T	Alum-1	23.2	13.76	14.27	17.08	5.312	31.1036	17.08	17.56	0.68			
W13-F	Alum-1	19.620	19.490	19.560	19.550	0.067	0.340	19.550	18.323	1.515			
W1-F	Alum-2	96.750	86.980	95.120	92.970	5.249	5.650	92.970					
W2-T	Alum-2	61.68	63.61	63.86	63.05	1.191	1.89	63.05					
W2-F	Alum-2	44.870	55.990	57.980	52.950	7.065	13.340	52.950					
W3-T	Alum-2	39.31	40.99	38.24	39.52	1.386	3.51	39.52					
W3-F	Alum-2	38.890	39.970	34.250	37.700	3.040	8.060	37.700					
W4-T	Alum-2	33.29	33.17	36.2	34.22	1.716	5.02	34.22					
W4-F	Alum-2	41.110	39.530	40.820	40.490	0.842	2.080	40.490					
W5-T	Alum-2	51.73	51.71	52.8	51.91	0.335	0.64	51.91					
W5-F	Alum-2	21.600	21.980	21.990	21.860	0.226	1.040	21.860					
W6-T	Alum-2												
W6-F	Alum-2	13.580	13.290	13.380	13.410	0.149	1.110	13.410					
W7-T	Alum-2	8.359	7.24	7.348	7.649	0.6173	8.07	7.649					
W7-F	Alum-2	12.440	14.460	11.500	12.800	1.514	11.830	12.800					
W8-T	Alum-2	18.94	25.56	14.81	19.77	5.422	27.43	19.77					
W8-F	Alum-2	27.540	27.890	28.180	27.870	0.319	1.140	27.870					
W9-T	Alum-2	25.32	27.78	26.47	26.52	1.23	4.64	26.52					
W9-F	Alum-2	18.390	17.090	18.850	18.110	0.910	5.020	18.110					
W10-T	Alum-2	24.18	23.53	23.9	23.87	0.324	1.36	23.87					
W10-F	Alum-2	21.760	15.500	22.440	19.900	3.828	19.235	19.900					
W11-T	Alum-2	12.03	10.98	11.11	1.38	0.573	5.0351	1.38					
W11-F	Alum-2	13.530	13.220	12.510	13.090	0.527	4.026	13.090					
W12-T	Alum-2	13.34	11.02	13.67	12.63	1.445	11.3969	12.63					
W12-F	Alum-2	15.250	16.580	15.870	15.900	0.665	4.180	15.900					
W13-T	Alum-2	20.9	20.26	10.63	17.26	5.753	33.3232	17.26					
W13-F	Alum-2	16.760	16.980	16.140	16.630	0.435	2.615	16.630					
W1-F	Alum-3	95.810	103.100	100.300	99.750	3.696	3.700	99.750					
W2-T	Alum-3	62.31	66.27	67.17	65.25	2.587	3.96	65.25					
W2-F	Alum-3	47.130	46.280	45.780	46.400	0.686	1.480	46.400					
W3-T	Alum-3	40.76	41.2	42.66	41.54	0.997	2.4	41.54					
W3-F	Alum-3	28.320	26.220	29.690	28.080	1.745	6.220	28.080					
W4-T	Alum-3	30.62	24.2	25.14	26.65	3.47	13.02	26.65					
W4-F	Alum-3	41.720	40.660	42.680	41.690	1.014	2.430	41.690					
W5-T	Alum-3	33.24	34.36	32.64	33.41	0.872	2.61	33.41					
W5-F	Alum-3	22.830	24.080	23.090	23.330	0.660	2.830	23.330					
W6-T	Alum-3												
W6-F	Alum-3	11.230	7.420	11.520	10.060	2.290	22.760	10.060					
W7-T	Alum-3	7.242	7.326	6.836	7.135	0.262	3.67	7.135					
W7-F	Alum-3	13.580	12.520	15.770	13.960	1.661	11.900	13.960					
W8-T	Alum-3	26.61	27.28	26.87	26.92	0.339	1.26	26.92					
W8-F	Alum-3	28.620	28.050	27.020	27.900	0.809	2.900	27.900					
W9-T	Alum-3	27.78	27.29	28.26	27.78	0.486	1.75	27.78					
W9-F	Alum-3	20.610	20.750	22.190	21.180	0.876	4.130	21.180					
W10-T	Alum-3	27.36	25.8	36.83	26.66	0.79	2.96	26.66					
W10-F	Alum-3	81.050	76.720	82.510	80.090	3.008	3.756	80.090					
W11-T	Alum-3	11.75	7.425	5.748	8.308	3.0973	37.2809	8.308					
W11-F	Alum-3	14.270	13.820	14.530	14.210	0.360	2.534	14.210					
W12-T	Alum-3	14.4	14.25	14.63	14.43	0.194	1.3431	14.43					
W12-F	Alum-3	18.590	17.810	18.250	18.220	0.394	2.160	18.220					
W13-T	Alum-3	18.61	18.18	18.19	18.33	0.246	1.3443	18.33					
W13-F	Alum-3	19.430	18.360	18.580	18.790	0.563	2.996	18.790					

		Pb (Total)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-F	FS-1	921.100	902.700	923.300	915.700	11.310	1.240	915.700	828.333	283.628	W1	828.333	283.628
W2-T	FS-1	390.3	378	358.2	375.5	16.22	4.32	375.5	439.83	88.61	W2	370.45	115.23
W2-F	FS-1	194.500	192.300	193.500	193.400	1.120	0.580	193.400	301.067	104.418	W3	238.817	121.824
W3-T	FS-1	177.8	176	180.5	178.1	2.26	1.27	178.1	256.60	119.31	W4	206.68	113.61
W3-F	FS-1	107.700	111.200	107.200	108.700	2.160	1.990	108.700	221.033	148.049	W5	154.917	92.479
W4-T	FS-1	95.55	97.29	98.17	97	1.332	1.37	97	209.87	130.26	W6	101.27	73.23
W4-F	FS-1	103.500	104.300	103.800	103.900	0.380	0.370	103.900	203.500	123.581	W7	112.433	57.961
W5-T	FS-1	102	101	102.5	101.8	0.78	0.77	101.8	193.63	116.95	W8	149.11	99.75
W5-F	FS-1	76.770	78.960	79.570	78.430	1.470	1.870	78.430	116.200	56.619	W9	157.295	115.963
W6-T	FS-1									#DIV/0!	W10	91.98	70.44
W6-F	FS-1	54.410	54.880	55.630	54.980	0.618	1.120	54.980	101.270	73.232	W11	64.085	69.135
W7-T	FS-1	74.12	71.99	75.42	73.84	1.729	2.34	73.84	113.99	67.57	W12	89.16	69.13
W7-F	FS-1	72.400	80.290	73.060	75.250	4.379	5.820	75.250	110.877	61.854	W13	100.202	74.540
W8-T	FS-1	76.65	78.05	82.72	79.14	3.179	4.02	79.14	165.44	140.62	W14	91.04	95.40
W8-F	FS-1	97.030	95.529	95.190	95.940	0.967	1.010	95.940	132.777	65.586			
W9-T	FS-1	95.86	94.15	95.29	95.1	0.873	0.92	95.1	190.07	156.42	W14	105.78	95.37
W9-F	FS-1	78.020	77.370	77.450	77.610	0.351	0.450	77.610	124.523	77.009	W15	130.228	116.904
W10-T	FS-1	57.34	58.29	59.46	58.36	1.062	1.82	58.36	97.39	70.44	W16	115.83	96.79
W10-F	FS-1	43.290	22.860	45.430	44.530	1.106	2.485	44.530	86.560	76.095	W17	106.524	137.980
W11-T	FS-1	23.93	16.16	24.37	21.49	4.619	21.4954	21.49	48.04	44.78	W18	153.00	141.76
W11-F	FS-1	42.760	43.630	42.610	43.000	0.550	1.279	43.000	80.133	69.135	W19	91.903	98.181
W12-T	FS-1	37.86	36.96	38.4	37.74	0.73	1.9342	37.74	92.05	97.14			
W12-F	FS-1	46.910	46.450	47.780	47.050	0.675	1.435	47.050	86.267	68.793			
W13-T	FS-1	52.26	36.06	52.39	46.91	9.389	20.0165	46.91	98.68	81.57			
W13-F	FS-1	56.860	57.970	55.610	56.810	1.181	2.079	56.810	101.727	85.034			
W1-F	FS-2	492.600	497.900	543.400	511.300	27.970	5.470	511.300					
W2-T	FS-2	414.4	413.9	381	403.1	19.17	4.76	403.1					
W2-F	FS-2	307.700	301.800	314.100	307.900	6.160	2.000	307.900					
W3-T	FS-2	189.3	197.4	206.6	197.8	8.69	4.39	197.8					
W3-F	FS-2	156.500	181.000	159.500	165.600	13.380	8.080	165.600					
W4-T	FS-2	180.8	180.1	179.8	180.2	0.53	0.3	180.2					
W4-F	FS-2	159.600	160.900	174.000	164.800	7.990	4.850	164.800					
W5-T	FS-2	149.5	152.8	159	153.8	4.81	3.13	153.8					
W5-F	FS-2	84.800	92.000	89.550	88.870	3.665	4.130	88.870					
W6-T	FS-2												
W6-F	FS-2	65.390	61.520	62.480	63.130	2.014	3.190	63.130					
W7-T	FS-2	75.96	76.55	75.88	76.13	0.37	0.49	76.13					
W7-F	FS-2	74.290	71.510	79.430	75.080	4.020	5.350	75.080					
W8-T	FS-2	87.04	94.3	87.1	89.48	4.174	4.67	89.48					
W8-F	FS-2	92.520	96.110	93.040	93.890	1.940	2.070	93.890					
W9-T	FS-2	102.8	107.2	103.4	104.5	2.38	2.28	104.5					
W9-F	FS-2	87.600	79.710	80.380	82.560	4.371	5.290	82.560					
W10-T	FS-2	56.72	54.35	54.27	55.11	1.39	2.52	55.11					
W10-F	FS-2	41.820	40.190	40.230	40.750	0.928	2.278	40.750					
W11-T	FS-2	28.21	20.26	20.16	22.88	4.616	20.1761	22.88					
W11-F	FS-2	37.410	37.310	37.780	37.500	0.247	0.659	37.500					
W12-T	FS-2	34.96	34.61	33.02	34.2	1.033	3.0197	34.2					
W12-F	FS-2	46.560	46.220	45.380	46.050	0.609	1.323	46.050					
W13-T	FS-2	54.62	58.93	55.7	56.42	2.244	3.9769	56.42					
W13-F	FS-2	47.860	48.560	49.310	48.570	0.726	1.494	48.570					
W1-F	FS-3	1090.000	1068.000	1015.000	1058.000	39.000	3.680	1058.000					
W2-T	FS-3	541.6	539.7	541.4	540.9	1.03	0.19	540.9					
W2-F	FS-3	413.600	401.300	390.700	401.900	11.470	2.850	401.900					
W3-T	FS-3	383.5	398.2	400.1	393.9	9.12	2.31	393.9					
W3-F	FS-3	395.500	389.600	380.400	388.800	7.600	1.960	388.800					
W4-T	FS-3	346.7	362	348.7	352.4	8.33	2.36	352.4					
W4-F	FS-3	344.400	327.600	353.300	341.800	13.060	3.820	341.800					
W5-T	FS-3	328.9	325	322	325.3	3.43	1.05	325.3					
W5-F	FS-3	182.300	178.900	182.700	181.300	2.060	1.140	181.300					
W6-T	FS-3												
W6-F	FS-3	186.900	181.700	188.400	185.700	3.500	1.890	185.700					
W7-T	FS-3	192.2	190	193.9	192	1.99	1.03	192					
W7-F	FS-3	177.400	194.700	174.800	182.300	10.770	5.910	182.300					
W8-T	FS-3	343.5	345.4	294.2	327.7	29.05	8.86	327.7					
W8-F	FS-3	211.700	206.100	207.800	208.500	2.850	1.370	208.500					
W9-T	FS-3	368.7	381.5	361.5	370.6	10.14	2.74	370.6					
W9-F	FS-3	209.800	218.100	212.200	213.400	4.270	2.000	213.400					
W10-T	FS-3	180	176.3	179.9	178.7	2.1	1.18	178.7					
W10-F	FS-3	178.100	174.300	170.800	174.400	3.650	2.092	174.400					
W11-T	FS-3	97.82	101.4	100	99.74	1.785	1.7894	99.74					
W11-F	FS-3	158.300	162.700	158.800	159.900	2.430	1.518	159.900					
W12-T	FS-3	210.3	206.1	196.2	204.2	7.23	3.5413	204.2					
W12-F	FS-3	165.400	163.300	168.500	165.700	2.610	1.578	165.700					
W13-T	FS-3	186.2	191.7	200.3	192.7	7.13	3.6982	192.7					
W13-F	FS-3	203.700	197.000	198.700	199.800	3.490	1.746	199.800					

		Pb (Total)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-F	PACl-1	215.800	225.100	222.500	221.100	4.780	2.160	221.100	298.100	68.285	W1	298.100	68.285
W2-T	PACl-1	194.7	195.4	184.4	191.5	6.17	3.22	191.5	175.50	16.41	W2	198.77	61.43
W2-F	PACl-1	175.400	169.300	168.800	171.200	3.635	2.130	171.200	222.033	86.836	W3	147.333	46.058
W3-T	PACl-1	180.5	181.5	189.5	183.9	4.94	2.69	183.9	159.30	44.35	W4	123.17	45.35
W3-F	PACl-1	100.800	102.600	105.400	102.900	2.300	2.240	102.900	135.367	53.913	W5	111.105	31.316
W4-T	PACl-1	98.69	98.34	97.43	98.15	0.648	0.66	98.15	120.63	55.93	W6	81.59	12.77
W4-F	PACl-1	104.200	104.200	102.900	103.800	0.760	0.730	103.800	125.710	44.666	W7	77.687	13.088
W5-T	PACl-1	108.7	107	106.5	107.4	1.16	1.08	107.4	127.60	39.67	W8	99.09	27.68
W5-F	PACl-1	90.670	92.030	92.810	91.830	1.084	1.180	91.830	94.610	7.877	W9	118.893	26.093
W6-T	PACl-1									#DIV/0!	W10	90.30	15.78
W6-F	PACl-1	74.390	76.140	72.500	74.350	1.817	2.440	74.350	81.590	12.766	W11	64.337	7.380
W7-T	PACl-1	66.75	66.84	65.6	66.4	0.689	1.04	66.4	70.38	11.64	W12	73.07	7.38
W7-F	PACl-1	89.390	70.450	86.870	82.240	10.284	12.510	82.240	84.990	11.524	W13	68.937	7.346
W8-T	PACl-1	83.7	73.06	86.61	81.12	7.138	8.8	81.12	79.87	4.83	W14	20.80	0.55
W8-F	PACl-1	106.600	104.300	106.000	105.700	1.220	1.150	105.700	118.320	27.992			
W9-T	PACl-1	104.2	105.9	106.8	105.6	1.3	1.23	105.6	119.93	29.72	W14	24.67	1.94
W9-F	PACl-1	106.800	105.100	106.600	106.200	0.930	0.880	106.200	117.853	28.562	W15	73.198	59.488
W10-T	PACl-1	120.4	120.9	117.5	119.6	1.88	1.57	119.6	114.90	15.78	W16	71.84	22.63
W10-F	PACl-1	63.560	71.380	69.890	68.270	4.153	6.083	68.270	65.707	6.647	W17	57.674	18.046
W11-T	PACl-1	63.24	61.7	62.97	62.63	0.822	1.3125	62.63	65.53	8.52	W18	50.11	23.88
W11-F	PACl-1	63.730	63.840	60.560	62.710	1.861	2.968	62.710	63.143	7.380	W19	29.380	23.671
W12-T	PACl-1	67.63	66.12	69.29	67.68	1.589	2.3473	67.68	65.63	9.90			
W12-F	PACl-1	80.720	79.680	78.650	79.680	1.037	1.302	79.680	80.520	5.181			
W13-T	PACl-1	70.91	58.51	71.1	66.84	7.217	10.7974	66.84	66.04	7.51			
W13-F	PACl-1	74.620	72.750	74.490	73.950	1.040	1.407	73.950	71.837	7.303			
W1-F	PACl-2	373.100	329.200	351.700	351.300	21.960	6.250	351.300					
W2-T	PACl-2	184.4	181.5	163.1	176.3	11.54	6.54	176.3					
W2-F	PACl-2	297.700	301.300	367.900	322.300	39.540	12.270	322.300					
W3-T	PACl-2	188.1	192.9	176.8	185.9	8.24	4.43	185.9					
W3-F	PACl-2	104.400	108.300	104.300	105.600	2.300	2.180	105.600					
W4-T	PACl-2	194.1	175.4	183.1	184.3	9.24	5.01	184.3					
W4-F	PACl-2	178.400	175.600	177.400	177.100	1.430	0.810	177.100					
W5-T	PACl-2	179	170.1	170.9	173.3	4.9	2.83	173.3					
W5-F	PACl-2	101.700	102.300	106.500	103.500	2.610	2.520	103.500					
W6-T	PACl-2												
W6-F	PACl-2	95.600	96.190	97.190	96.330	0.805	0.840	96.330					
W7-T	PACl-2	83.9	82.97	83.6	83.49	0.472	0.56	83.49					
W7-F	PACl-2	102.600	89.900	100.400	97.640	6.789	6.950	97.640					
W8-T	PACl-2	77.28	97.56	77.03	83.95	11.781	14.03	83.95					
W8-F	PACl-2	149.400	152.700	149.200	150.400	1.960	1.300	150.400					
W9-T	PACl-2	155.2	150.3	156.7	154.1	3.31	2.15	154.1					
W9-F	PACl-2	150.300	151.400	149.600	150.400	0.880	0.580	150.400					
W10-T	PACl-2	133.8	125	124.4	127.8	5.24	4.1	127.8					
W10-F	PACl-2	67.950	72.990	71.130	70.690	2.548	3.604	70.690					
W11-T	PACl-2	74.16	77.7	73.49	75.12	2.264	3.0138	75.12					
W11-F	PACl-2	69.350	71.650	71.200	70.730	1.218	1.722	70.730					
W12-T	PACl-2	76.88	74.68	71.46	74.34	2.725	3.6657	74.34					
W12-F	PACl-2	86.980	87.130	84.090	86.070	1.711	1.988	86.070					
W13-T	PACl-2	69.56	75.29	74.48	73.11	3.103	4.2447	73.11					
W13-F	PACl-2	77.650	79.310	76.600	77.850	1.369	1.758	77.850					
W1-F	PACl-3	317.500	324.000	324.100	321.900	3.780	1.170	321.900					
W2-T	PACl-3	160.3	160.8	155	158.7	3.22	2.03	158.7					
W2-F	PACl-3	169.600	1277.900	170.200	172.600	4.620	2.638	172.600					
W3-T	PACl-3	106.7	109.4	108.3	108.1	1.38	1.27	108.1					
W3-F	PACl-3	+	189.300	205.200	197.600	7.970	4.040	197.600					
W4-T	PACl-3	79.86	82.41	76.04	79.44	3.206	4.04	79.44					
W4-F	PACl-3	96.000	97.040	95.650	96.230	0.720	0.750	96.230					
W5-T	PACl-3	102.1	100.4	103.9	102.1	1.77	1.73	102.1					
W5-F	PACl-3	86.900	87.890	90.700	88.500	1.973	2.230	88.500					
W6-T	PACl-3												
W6-F	PACl-3	73.880	72.990	75.410	74.090	1.226	1.650	74.090					
W7-T	PACl-3	62.68	60.34	60.76	61.26	1.25	2.04	61.26					
W7-F	PACl-3	77.780	77.980	69.520	75.090	4.829	6.430	75.090					
W8-T	PACl-3	76.5	76.17	70.91	74.53	3.139	4.21	74.53					
W8-F	PACl-3	102.600	97.440	96.440	98.860	3.307	3.340	98.860					
W9-T	PACl-3	98.39	100.6	101.2	100.1	1.48	1.48	100.1					
W9-F	PACl-3	96.180	97.220	97.480	96.960	0.690	0.710	96.960					
W10-T	PACl-3	98.14	96.7	97.06	97.3	0.748	0.77	97.3					
W10-F	PACl-3	58.090	61.750	54.630	58.160	3.563	6.126	58.160					
W11-T	PACl-3	59.53	58.22	58.76	58.84	0.661	1.1235	58.84					
W11-F	PACl-3	58.140	51.440	58.380	55.990	3.940	7.038	55.990					
W12-T	PACl-3	58.23	53.13	53.21	54.86	2.921	5.3252	54.86					
W12-F	PACl-3	76.570	74.610	76.250	75.810	1.052	1.388	75.810					
W13-T	PACl-3	64.64	54.09	55.76	58.16	5.672	9.7526	58.16					
W13-F	PACl-3	65.140	64.720	61.270	63.710	2.122	3.331	63.710					

Table D2. Low CSMR

		Pb (Dissolved)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-F	Alum-1	70.990	69.220	64.000	68.070	3.635		68.070	59.137	7.766	W1	59.137	7.766
W2-T	Alum-1	36.98	43.27	43.31	41.19	3.643	8.84	41.19	36.10	4.60	W2	32.02	6.90
W2-F	Alum-1	33.600	37.800	36.170	35.850	2.119	5.910	35.850	27.930	6.922	W3	17.918	7.922
W3-T	Alum-1	28.37	32.44	28.14	29.65	2.421	8.16	29.65	21.94	6.96	W4	19.26	6.69
W3-F	Alum-1	21.240	18.210	28.990	22.810	5.556	24.350	22.810	13.898	7.742	W5	18.668	7.411
W4-T	Alum-1	17.65	14.21	15.85	15.9	1.722	10.83	15.9	13.73	2.06	W6	6.30	4.04
W4-F	Alum-1	29.470	29.100	29.640	29.400	0.273	0.930	29.400	24.787	3.995	W7	5.453	3.115
W5-T	Alum-1	30.38	30.41	29.3	30.03	0.634	2.11	30.03	24.23	5.33	W8	15.23	6.13
W5-F	Alum-1	17.940	17.810	17.320	17.690	0.327	1.850	17.690	13.103	4.000	W9	17.325	5.554
W6-T	Alum-1								#DIV/0!	#DIV/0!	W10	10.80	2.51
W6-F	Alum-1	11.880	9.896	10.370	10.720	1.035	9.660	10.720	6.304	4.036	W11	6.562	1.204
W7-T	Alum-1	8.458	6.692	6.153	7.101	1.2061	16.98	7.101	3.75	2.91	W12	11.08	1.20
W7-F	Alum-1	-	-	-	-	-	-	-	8.010	0.340	W13	1.761	4.637
W8-T	Alum-1	14.36	15.94	9.482	13.26	3.368	25.39	13.26	10.28	3.00	W14	2.42	2.67
W8-F	Alum-1	23.180	24.930	23.590	23.900	0.917	3.840	23.900	20.183	3.355			
W9-T	Alum-1	26.09	25.39	26.06	25.85	0.398	1.54	25.85	21.45	3.84	W14	0.62	1.96
W9-F	Alum-1	17.380	17.280	16.550	17.070	0.451	2.640	17.070	13.197	3.357	W15	9.473	3.991
W10-T	Alum-1	14.59	14.58	13.95	14.37	0.369	2.57	14.37	11.57	2.51	W16	14.16	4.89
W10-F	Alum-1	2.576	1.495	2.313	2.128	0.564	26.483	2.128	10.025	13.584	W17	7.562	3.867
W11-T	Alum-1	6.344	4.871	5.956	5.724	0.7636	13.3417	5.724	4.03	1.62	W18	8.27	3.49
W11-F	Alum-1	10.340	10.420	10.690	10.480	0.182	1.740	10.480	9.094	1.204	W19	6.709	2.517
W12-T	Alum-1	12.8	15.08	12.54	13.47	1.396	10.3659	13.47	11.19	2.02			
W12-F	Alum-1	11.580	10.730	10.280	10.860	0.658	6.059	10.860	10.966	4.152			
W13-T	Alum-1	6.009	7.138	3.023	5.39	2.1263	39.4426	5.39	3.86	1.34			
W13-F	Alum-1	-5.972	-6.774	-7.228	-6.658	0.636	9.550	-6.658	-0.340	6.224			
W1-F	Alum-2	53.370	53.990	54.610	53.990	0.619	1.150	53.990					
W2-T	Alum-2	31.74	32.31	32.67	32.24	0.466	1.44	32.24					
W2-F	Alum-2	22.310	26.570	25.820	24.900	2.273	9.130	24.900					
W3-T	Alum-2	19.71	20.3	20.13	20.05	0.305	1.52	20.05					
W3-F	Alum-2	8.435	9.390	12.320	10.050	2.026	20.160	10.050					
W4-T	Alum-2	13.66	15.34	11.45	13.49	1.951	14.46	13.49					
W4-F	Alum-2	24.120	23.880	21.840	22.480	0.728	3.240	22.480					
W5-T	Alum-2	22.78	23.09	23.51	23.12	0.365	1.58	23.12					
W5-F	Alum-2	11.570	11.090	11.180	11.280	0.254	2.250	11.280					
W6-T	Alum-2												
W6-F	Alum-2	6.317	5.696	4.105	5.386	1.119	20.770	5.386					
W7-T	Alum-2	2.424	2.411	1.84	2.225	0.3335	14.99	2.225					
W7-F	Alum-2	8.496	7.323	8.958	8.250	0.839	10.170	8.250					
W8-T	Alum-2	11.55	11.75	7.617	10.31	2.332	22.62	10.31					
W8-F	Alum-2	19.250	18.990	19.570	19.270	0.289	1.500	19.270					
W9-T	Alum-2	19.93	19.25	20	19.73	0.414	2.1	19.73					
W9-F	Alum-2	11.640	11.600	10.190	11.140	0.825	7.400	11.140					
W10-T	Alum-2	11.02	11.22	10.19	10.81	0.546	5.05	10.81					
W10-F	Alum-2	1.168	2.138	3.403	2.237	1.121	50.113	2.237					
W11-T	Alum-2	3.863	2.065	4.557	2.495	1.2861	36.7949	2.495					
W11-F	Alum-2	8.639	7.607	8.707	8.317	0.617	7.412	8.317					
W12-T	Alum-2	10.67	10.85	7.313	9.611	1.9927	20.733	9.611					
W12-F	Alum-2	7.430	5.802	7.374	6.869	0.924	13.454	6.869					
W13-T	Alum-2	3.65	3.217	3.03	3.299	0.3182	9.6459	3.299					
W13-F	Alum-2	-0.152	-0.101	-0.184	-0.146	0.042	28.860	-0.146					
W1-F	Alum-3	54.670	54.610	56.870	55.350	1.317	2.380	55.350					
W2-T	Alum-3	34.43	35.32	34.88	34.88	0.445	1.28	34.88					
W2-F	Alum-3	21.980	22.380	24.750	23.040	1.496	6.490	23.040					
W3-T	Alum-3	16.11	15.19	17.03	16.11	0.919	5.7	16.11					
W3-F	Alum-3	8.756	9.344	8.404	8.835	0.475	5.380	8.835					
W4-T	Alum-3	9.361	10.9	15.18	11.81	3.017	25.54	11.81					
W4-F	Alum-3	23.270	22.340	21.840	22.480	0.728	3.240	22.480					
W5-T	Alum-3	20.2	19.42	19.04	19.55	0.592	3.03	19.55					
W5-F	Alum-3	10.950	10.320	9.754	10.340	0.599	5.790	10.340					
W6-T	Alum-3												
W6-F	Alum-3	2.261	2.296	3.862	2.807	0.915	32.590	2.807					
W7-T	Alum-3	2.658	2.024	1.073	1.918	0.7975	41.57	1.918					
W7-F	Alum-3	7.593	6.726	8.990	7.769	1.143	14.710	7.769					
W8-T	Alum-3	8.548	5.556	7.694	7.266	1.5416	21.22	7.266					
W8-F	Alum-3	17.000	17.640	17.500	17.380	0.338	1.940	17.380					
W9-T	Alum-3	18.75	19.27	18.32	18.78	0.475	2.53	18.78					
W9-F	Alum-3	11.610	12.130	10.380	11.380	0.901	7.920	11.380					
W10-T	Alum-3	9.429	9.732	9.421	9.527	0.1774	1.86	9.527					
W10-F	Alum-3	24.720	26.620	25.800	25.710	0.954	3.711	25.710					
W11-T	Alum-3	4.195	3.436	3.99	3.874	0.3925	10.1342	3.874					
W11-F	Alum-3	8.172	8.941	8.340	8.484	0.404	4.764	8.484					
W12-T	Alum-3	9.616	9.091	12.75	10.48	1.977	18.8548	10.48					
W12-F	Alum-3	15.420	14.800	15.280	15.170	0.328	2.163	15.170					
W13-T	Alum-3	3.785	1.329	3.567	2.894	1.3596	46.9842	2.894					
W13-F	Alum-3	7.616	3.102	6.637	5.785	2.375	41.044	5.785					

		Pb (Dissolved)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-F	FS-1	282.400	276.800	291.200	283.400	7.250	2.560	283.400	166.667	101.145	W1	166.667	101.145
W2-T	FS-1	105.6	106.5	106.2	106.1	0.46	0.43	106.1	202.23	113.74	W2	162.17	90.83
W2-F	FS-1	81.370	78.550	80.760	80.230	1.483	1.850	80.230	122.110	53.589	W3	127.997	58.912
W3-T	FS-1	94.73	95.24	93.88	94.62	0.686	0.73	94.62	141.37	68.18	W4	105.23	59.40
W3-F	FS-1	80.810	74.370	74.680	76.620	3.633	4.740	76.620	114.620	59.092	W5	87.420	38.801
W4-T	FS-1	55.72	57.24	55.74	53.23	0.873	1.55	53.23	106.28	70.82	W6	58.95	31.75
W4-F	FS-1	63.330	62.410	64.060	63.260	0.826	1.310	63.260	104.170	61.668	W7	34.310	28.733
W5-T	FS-1	68.82	69.42	67.84	68.69	0.801	1.17	68.69	104.71	50.55	W8	49.29	29.08
W5-F	FS-1	56.190	54.670	53.910	54.920	1.160	2.110	54.920	70.127	17.643	W9	63.812	59.417
W6-T	FS-1								#DIV/0!	#DIV/0!	W10	38.89	38.83
W6-F	FS-1	34.820	36.120	35.960	35.630	0.708	1.990	35.630	58.947	31.753	W11	36.497	33.891
W7-T	FS-1	27.89	26.26	26.34	26.83	0.918	3.42	26.83	49.13	36.92	W12	43.80	33.89
W7-F	FS-1	23.530	23.330	22.070	22.980	0.792	3.450	22.980	19.493	6.512	W13	37.026	38.723
W8-T	FS-1	28.15	28.7	26.9	27.92	0.921	3.3	27.92	50.03	37.78	W14	32.11	43.95
W8-F	FS-1	35.680	33.320	34.410	34.470	1.181	3.430	34.470	48.553	26.162			
W9-T	FS-1	38.18	35.53	36.6	36.77	1.335	3.63	36.77	83.40	76.26	W14	30.88	47.73
W9-F	FS-1	19.000	17.630	18.220	18.280	0.688	3.760	18.280	44.227	43.127	W15	40.698	47.230
W10-T	FS-1	15.72	13.69	14.98	14.8	1.027	6.94	14.8	38.41	38.83	W16	31.89	38.33
W10-F	FS-1	20.770	20.710	19.780	20.420	0.558	2.734	20.420	39.360	33.553	W17	39.221	72.084
W11-T	FS-1	12.82	12.53	10.85	12.07	1.064	8.8194	12.07	35.10	38.99	W18	43.49	65.78
W11-F	FS-1	20.030	19.020	20.220	19.760	0.641	3.245	19.760	37.890	33.891	W19	26.900	47.069
W12-T	FS-1	19.49	17.45	19.09	18.68	1.082	5.7945	18.68	45.69	50.37			
W12-F	FS-1	19.860	20.810	19.500	20.060	0.678	3.382	20.060	41.913	40.946			
W13-T	FS-1	8.673	8.873	8.304	8.616	0.2887	3.3505	8.616	36.03	38.99			
W13-F	FS-1	12.300	11.860	10.840	11.670	0.746	6.395	11.670	38.026	47.175			
W1-F	FS-2	105.900	113.000	115.600	111.500	5.050	4.530	111.500					
W2-T	FS-2	185.3	163.6	169.5	172.8	11.23	6.5	172.8					
W2-F	FS-2	101.000	110.600	99.350	103.600	6.050	5.840	103.600					
W3-T	FS-2	106.2	107.8	115.6	109.9	4.98	4.53	109.9					
W3-F	FS-2	85.320	84.370	83.430	84.540	0.969	1.170	84.540					
W4-T	FS-2	76.09	81.36	79.28	78.91	2.656	3.37	78.91					
W4-F	FS-2	74.530	74.440	73.490	74.150	0.577	0.780	74.150					
W5-T	FS-2	82.97	83.21	82.66	82.95	0.272	0.33	82.95					
W5-F	FS-2	67.420	64.560	65.990	65.990	1.427	2.160	65.990					
W6-T	FS-2												
W6-F	FS-2	45.980	47.620	44.700	46.100	1.465	3.180	46.100					
W7-T	FS-2	27.92	28.79	29.71	28.81	0.894	3.1	28.81					
W7-F	FS-2	23.360	23.310	23.890	23.520	0.320	1.360	23.520					
W8-T	FS-2	24.46	36.65	24.43	28.52	7.048	24.72	28.52					
W8-F	FS-2	32.650	32.390	32.300	32.450	0.185	0.570	32.450					
W9-T	FS-2	42.49	41.4	42.8	42.02	0.562	1.34	42.02					
W9-F	FS-2	21.400	20.410	19.360	20.390	1.024	5.020	20.390					
W10-T	FS-2	17.76	16	17.87	17.21	1.048	6.09	17.21					
W10-F	FS-2	18.560	18.330	21.800	19.560	1.943	9.930	19.560					
W11-T	FS-2	13.14	13.09	13.12	13.12	0.024	0.1853	13.12					
W11-F	FS-2	17.540	16.790	16.440	16.920	0.563	3.325	16.920					
W12-T	FS-2	13.47	15.23	15.04	14.58	0.962	6.5963	14.58					
W12-F	FS-2	15.610	16.780	17.200	16.530	0.823	4.976	16.530					
W13-T	FS-2	18.72	20.03	17.65	18.8	1.191	6.3328	18.8					
W13-F	FS-2	9.794	10.140	9.822	9.918	0.192	1.934	9.918					
W1-F	FS-3	106.000	103.600	105.800	105.100	1.290	1.230	105.100					
W2-T	FS-3	317.1	377.1	289.2	327.8	45.01	13.73	327.8					
W2-F	FS-3	186.300	178.100	183.100	182.500	4.150	2.270	182.500					
W3-T	FS-3	199.3	227.9	231.6	219.6	17.66	8.04	219.6					
W3-F	FS-3	176.800	189.500	181.600	182.700	6.420	3.510	182.700					
W4-T	FS-3	202.8	158.8	198.6	186.7	24.27	13	186.7					
W4-F	FS-3	177.800	171.500	175.900	175.100	3.220	1.840	175.100					
W5-T	FS-3	160.2	162.6	164.7	162.5	2.25	1.38	162.5					
W5-F	FS-3	90.460	89.170	88.780	89.470	0.880	0.980	89.470					
W6-T	FS-3												
W6-F	FS-3	98.040	93.920	93.360	95.110	2.557	2.690	95.110					
W7-T	FS-3	90.81	92.79	91.62	91.74	0.999	1.09	91.74					
W7-F	FS-3	12.490	11.890	11.570	11.980	0.470	3.920	11.980					
W8-T	FS-3	84.75	100.9	95.32	93.66	8.2	8.75	93.66					
W8-F	FS-3	77.110	77.660	81.440	78.740	2.354	2.990	78.740					
W9-T	FS-3	171.9	170.7	171.5	171.4	0.63	0.37	171.4					
W9-F	FS-3	97.730	89.920	94.400	94.010	3.919	4.170	94.010					
W10-T	FS-3	84.06	82.65	83.23	83.23	0.711	0.85	83.23					
W10-F	FS-3	87.830	68.460	78.020	78.100	9.684	12.399	78.100					
W11-T	FS-3	81.93	78.09	80.35	80.12	1.933	2.4121	80.12					
W11-F	FS-3	76.700	78.110	76.170	76.990	1.005	1.305	76.990					
W12-T	FS-3	104	104.5	103	103.8	0.8	0.7704	103.8					
W12-F	FS-3	89.460	88.390	89.600	89.150	0.664	0.745	89.150					
W13-T	FS-3	95.15	73.45	73.37	80.66	12.548	15.5579	80.66					
W13-F	FS-3	92.920	91.080	93.440	92.490	1.240	1.340	92.490					

		Pb (Dissolved)											
Week ID	Sample ID	1	2	3	Mean	SD	%RSD	Average Pb (per pipe)	Daily Average (Triplicate Pipe Type)	Std. dev.	Week	Weekly Average (Pipe Type)	Std. Dev.
W1-F	PACl-1	55.590	56.000	57.130	56.250	0.795	1.410	56.250	60.680	8.402	W1	60.680	8.402
W2-T	PACl-1	57.5	64.43	63.15	61.69	3.688	5.98	61.69	67.28	5.24	W2	67.57	4.98
W2-F	PACl-1	66.710	63.910	65.930	65.520	1.450	2.210	65.520	67.853	5.859	W3	61.570	8.282
W3-T	PACl-1	62.22	60.58	64.4	62.4	1.916	3.07	62.4	65.46	9.07	W4	60.43	18.09
W3-F	PACl-1	51.650	49.040	52.630	51.510	1.854	3.630	51.510	57.680	6.624	W5	73.495	15.738
W4-T	PACl-1	36.31	31.95	34.28	34.18	2.181	6.38	34.18	45.76	10.89	W6	52.04	9.77
W4-F	PACl-1	68.570	68.510	70.310	69.130	1.022	1.480	69.130	75.093	7.347	W7	46.833	9.334
W5-T	PACl-1	77.3	78.31	77.7	77.77	0.507	0.65	77.77	85.23	10.89	W8	65.39	17.46
W5-F	PACl-1	60.120	59.970	58.857	59.650	0.685	1.150	59.650	61.757	9.340	W9	65.453	11.877
W6-T	PACl-1								#DIV/0!	#DIV/0!	W10	47.69	14.53
W6-F	PACl-1	45.360	46.010	46.610	45.990	0.626	1.360	45.990	52.043	9.775	W11	47.602	5.808
W7-T	PACl-1	39.57	39.96	41	40.18	0.736	1.83	40.18	44.58	8.37	W12	44.58	5.81
W7-F	PACl-1	39.020	38.250	48.690	41.980	5.819	13.860	41.980	49.087	11.513	W13	26.103	8.426
W8-T	PACl-1	47.29	48.94	48.18	48.114	0.827	1.72	48.114	51.18	3.56	W14	5.13	0.24
W8-F	PACl-1	74.960	77.510	76.090	76.180	1.278	1.680	76.180	79.597	12.005			
W9-T	PACl-1	65.43	61.49	63.48	63.47	1.97	3.1	63.47	70.33	13.95	W14	-1.33	0.39
W9-F	PACl-1	61.830	56.710	57.850	58.800	2.689	4.570	58.800	60.577	9.313	W15	23.020	22.847
W10-T	PACl-1	47.07	50.49	47.28	48.28	1.915	3.97	48.28	55.48	14.53	W16	30.85	7.57
W10-F	PACl-1	39.120	39.850	39.300	39.420	0.379	0.961	39.420	39.897	7.896	W17	31.422	10.776
W11-T	PACl-1	48.7	47.46	46.53	47.57	1.089	2.2901	47.57	50.63	4.50	W18	8.89	53.59
W11-F	PACl-1	42.050	41.520	42.380	41.980	0.431	1.028	41.980	44.577	5.808	W19	28.850	7.493
W12-T	PACl-1	54.78	51.33	54.31	53.48	1.871	3.4984	53.48	50.27	10.71			
W12-F	PACl-1	50.870	45.180	46.730	47.590	2.939	6.176	47.590	51.417	6.302			
W13-T	PACl-1	22.33	27.44	30.66	26.81	4.2	15.6635	26.81	31.26	8.63			
W13-F	PACl-1	22.410	22.400	22.230	22.340	0.097	0.436	22.340	20.943	4.810			
W1-F	PACl-2	67.530	70.700	72.870	70.370	2.683	3.810	70.370					
W2-T	PACl-2	70.83	74.82	70.57	72.08	2.38	3.3	72.08					
W2-F	PACl-2	68.800	78.450	76.310	74.520	5.070	6.800	74.520					
W3-T	PACl-2	69.94	78.87	78.15	75.66	4.961	6.56	75.66					
W3-F	PACl-2	64.620	64.840	64.580	64.680	0.140	0.220	64.680					
W4-T	PACl-2	57.13	54.45	55.82	55.8	1.34	2.4	55.8					
W4-F	PACl-2	85.970	79.340	84.610	83.300	3.500	4.200	83.300					
W5-T	PACl-2	97.34	97.83	98.01	97.73	0.349	0.36	97.73					
W5-F	PACl-2	71.130	71.810	72.980	71.970	0.938	1.300	71.970					
W6-T	PACl-2												
W6-F	PACl-2	63.090	64.420	62.440	63.320	1.009	1.590	63.320					
W7-T	PACl-2	53.39	55.11	54.18	54.23	0.859	1.58	54.23					
W7-F	PACl-2	61.950	62.750	62.400	62.370	0.398	0.640	62.370					
W8-T	PACl-2	56.86	54.48	53.94	55.09	1.556	2.82	55.09					
W8-F	PACl-2	91.380	92.700	94.750	92.940	1.699	1.830	92.940					
W9-T	PACl-2	84.93	84.79	86.42	86.38	0.904	1.06	86.38					
W9-F	PACl-2	70.470	71.840	69.630	70.650	1.119	1.580	70.650					
W10-T	PACl-2	67.34	72.96	76.3	72.2	4.524	6.27	72.2					
W10-F	PACl-2	48.190	48.100	47.780	48.020	0.212	0.442	48.020					
W11-T	PACl-2	54.88	56.67	56.05	55.8	1.02	1.8282	55.8					
W11-F	PACl-2	51.950	51.130	50.590	51.230	0.683	1.333	51.230					
W12-T	PACl-2	63.17	48.73	65.11	59.01	8.951	15.169	59.01					
W12-F	PACl-2	57.830	57.970	60.280	58.690	1.378	2.348	58.690					
W13-T	PACl-2	48.76	37.45	37.43	41.21	6.536	15.8609	41.21					
W13-F	PACl-2	25.940	24.770	24.000	24.900	0.978	3.926	24.900					
W1-F	PACl-3	47.430	57.070	61.760	55.420	7.306	13.180	55.420					
W2-T	PACl-3	73.69	65.81	64.69	68.06	4.908	7.21	68.06					
W2-F	PACl-3	61.370	67.650	61.550	63.520	3.578	5.630	63.520					
W3-T	PACl-3	56.69	59.28	58.97	58.32	1.414	2.43	58.32					
W3-F	PACl-3	53.980	54.890	61.670	56.850	4.201	7.390	56.850					
W4-T	PACl-3	46.82	47.23	47.87	47.31	0.532	1.12	47.31					
W4-F	PACl-3	73.050	73.040	72.470	72.850	0.331	0.450	72.850					
W5-T	PACl-3	81.28	80.55	78.76	80.2	1.297	1.62	80.2					
W5-F	PACl-3	53.050	54.920	52.970	53.650	1.106	2.060	53.650					
W6-T	PACl-3												
W6-F	PACl-3	45.740	48.730	45.990	46.820	1.660	3.550	46.820					
W7-T	PACl-3	39.05	40.1	38.84	39.33	0.673	1.71	39.33					
W7-F	PACl-3	43.520	44.040	41.190	42.910	1.519	3.540	42.910					
W8-T	PACl-3	51.98	50.4	48.6	50.33	1.693	3.36	50.33					
W8-F	PACl-3	70.120	68.970	69.910	69.670	0.616	0.880	69.670					
W9-T	PACl-3	62.21	58.86	62.34	61.14	1.972	3.23	61.14					
W9-F	PACl-3	52.720	52.760	51.340	52.280	0.808	1.550	52.280					
W10-T	PACl-3	47.07	46.24	44.58	45.96	1.268	2.76	45.96					
W10-F	PACl-3	31.840	31.510	33.380	32.250	1.000	3.102	32.250					
W11-T	PACl-3	47.21	47.65	50.68	48.51	1.89	3.8952	48.51					
W11-F	PACl-3	38.750	41.040	41.760	40.520	1.575	3.887	40.520					
W12-T	PACl-3	37.47	41.4	36.14	38.33	2.733	7.129	38.33					
W12-F	PACl-3	48.310	48.470	46.130	47.970	1.650	3.440	47.970					
W13-T	PACl-3	31.33	23.7	22.29	25.77	4.867	18.883	25.77					
W13-F	PACl-3	15.740	15.220	15.810	15.590	0.321	2.062	15.590					