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To:	Jeff Cameron, Amy Blain – City of Longview	**Date:**	July 17, 2016
From:	Stephen Booth, Michael Hallett, and Melinda Friedman – Confluence	**Project:**	Softening Alternatives & Baltimore Street Water Quality Evaluation
Cc:		**Subject:**	In-Home DO Trials Technical Memorandum FINAL

Introduction and Objectives

Confluence previously evaluated dissolved oxygen (DO) addition during pipe rig testing at the MFRWTP, demonstrating notable improvement in iron, manganese, and color levels in the treated water after stagnation in unlined cast iron pipes. However, the effect of DO on chlorine levels was inconclusive, and sulfide levels were not tested since sulfide is not present in the MFRWTP finished water. Recent water quality evaluations performed at two homes indicated that the low oxidizing potential of the water delivered from the distribution system contributed to the development of sulfide and other objectionable tastes and odors.

The objective of this task was to evaluate the effect of increased DO on water quality within premise plumbing. The overall objective was to attempt to quantify water quality benefits that would be perceived by the homeowner, and as such, Flavor Rating Assessment (FRA), performed by a trained flavor profile panel at Seattle Public Utilities, was included. This document presents the testing approach, sampling plan, results, and conclusions.

Testing Approach

Commercially-available aeration equipment was obtained for this testing. The Pure Water Products, LLC Aeration System was designed to provide sufficient aeration to oxidize iron and sulfur upstream of a companion filtration unit. The equipment vendor could not provide information on the level of DO that would be achieved under a given set of operating conditions. The aerator was tested without the filtration unit at the MFRWTP by Confluence in an attempt to determine operating parameters which would have likely achieved the target range of 4 to 8 mg/L of DO within the homes. Those tests achieved DO levels ranging from 3.4 – 7.4 mg/L over a flowrate range of 0.5 – 5 gpm. The highest DO levels were obtained at the lowest flow rates. Similar aeration equipment from Kinetico® was selected for the actual in-home trials because the vendor could provide on-site support and provide troubleshooting services. The performance of the Kinetico® system was not comparable to the Pure Water Products aerator due to repeated equipment failures and the inability to monitor the equipment full time and continuously over the 3-month testing period. The actual level of DO achieved remained below the target range in this testing, as described below. Test units were installed in two homes as follows:

- Home A: 500 block of 19th Avenue in the Longview distribution system
- Home B: 100 block of Alpha Drive in the Beacon Hill Water and Sewer District service area

Approximately one week after the aeration equipment had been installed within each home, Confluence staff arrived on site to verify the DO level downstream of the equipment on that day. DO levels of approximately 6 mg/L were measured at both homes, but the water had a "milky" appearance. Confluence adjusted the operating settings to reduce the extent of aeration in an attempt to eliminate the milky appearance. Later during weekly site visits conducted by Longview staff, the DO level was found to have dropped below the target range of 4 to 8 mg/L and technicians employed by the equipment vendor were contacted by phone and later visited the homes to attempt to adjust the operating settings to increase the level of DO. Despite these efforts the units did not provide DO within the target range.

Sampling and Analysis Plan

Detailed water quality profiling and routine sample collection efforts are summarized below.

Detailed Water Quality Profiling

Detailed water quality profiling was performed prior to installation of the aeration equipment (pre-injection) on January 13 and 14, 2016 and repeated following approximately three months of operation of that equipment within each home (post-injection) on April 26, 2016. In order to standardize initial conditions, a stagnation period of 6 to 8 hours preceded sample collection. The sampling and analysis matrix is presented in Table 1. Sample collection and analysis were performed by Confluence staff.

Table 1. Detailed Water Quality Profiling Sampling and Analysis Matrix

		Kitchen Cold Tap				Bath Cold Tap		
Parameter	**D.S.[1]**	**1[2]**	**2[2]**	**3[2]**	**Flowing[3]**	**1[2]**	**2[2]**	**Bath Hot[4]**
Free Chlorine	✓	✓	✓	✓		✓	✓	✓
Total Chlorine	✓	✓	✓	✓		✓	✓	✓
Turbidity	✓	✓	✓	✓		✓	✓	✓
Apparent Color	✓	✓	✓	✓		✓	✓	✓
Iron, total	✓	✓	✓			✓		✓
Manganese, total	✓	✓	✓			✓		✓
ATP[5]	✓	✓	✓	✓		✓	✓	✓
Sulfide	✓		✓	✓		✓	✓	✓
FRA[5]	✓	✓						✓
DO	✓				✓			
pH	✓	✓			✓			
Temperature	✓	✓	✓	✓	✓	✓	✓	✓

Notes:

1. Collected at nearest distribution system hydrant.
2. Aliquots were 1-L in volume.
3. Following collection of three 1-L aliquots from kitchen faucet, water was allowed to flow for 2 to 3 minutes to verify DO, pH, and temperature.
4. 1-gallon sample collected from bathroom hot water faucet.
5. Cellular adenosine triphosphate (ATP) is an indicator of the extent of microbial activity.
6. FRA analyzed by Seattle Public Utilities.

Routine Sampling and Analysis Once Aeration Equipment was Installed and Operating

Following equipment installation, samples were collected approximately weekly by Longview staff, as presented in Table 2. For the weekly sampling, the water was allowed to continuously flow from the hose bib during sample collection. By conducting the weekly sampling at a hose bib, repeated entry into these

homes was avoided. A modified bucket with a short length of hose was used to provide representative water quality. FRA samples were collected by Longview staff after two months of operation of the aeration equipment on March 23, 2016 and those samples were analyzed by Seattle Public Utilities.

Table 2. Routine Water Quality Sampling Performed by Longview Staff

Parameter	Bi-Weekly Samples		After Two Months
	D.S.[1]	Hose Bib[2]	Kitchen Faucet
Free Chlorine	✓	✓	✓
Total Chlorine	✓	✓	✓
Turbidity	✓	✓	
Apparent Color	✓	✓	
Temperature	✓	✓	
DO	✓	✓	✓
ORP	✓	✓	
FRA			✓

Notes:

1. Collected at nearest hydrant.
2. Collected at hose bib outside of home to avoid repeated entry into home by City staff.

Results and discussion

Routine Water Quality Data

Weekly DO data collected during routine sampling at the hose bib of each home after the installation of the aeration equipment are presented in Figures 1 and 2 for Homes A and B, respectively. Slightly elevated DO was consistently observed at Home A compared to the distribution system samples collected at a hydrant near the home. DO levels remained well below the target range of 4 to 8 mg/L throughout the duration of this pilot test. There was more scatter in the DO data for Home B and DO levels within that home remained below the DO of the distribution system water for most of the duration of the test.

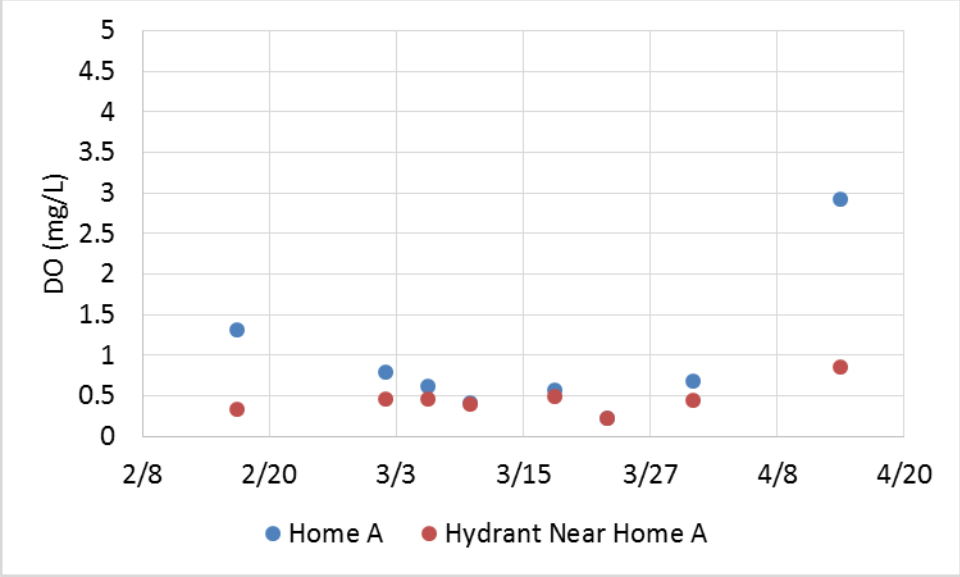

Figure 1. Routine weekly DO data for Home A.

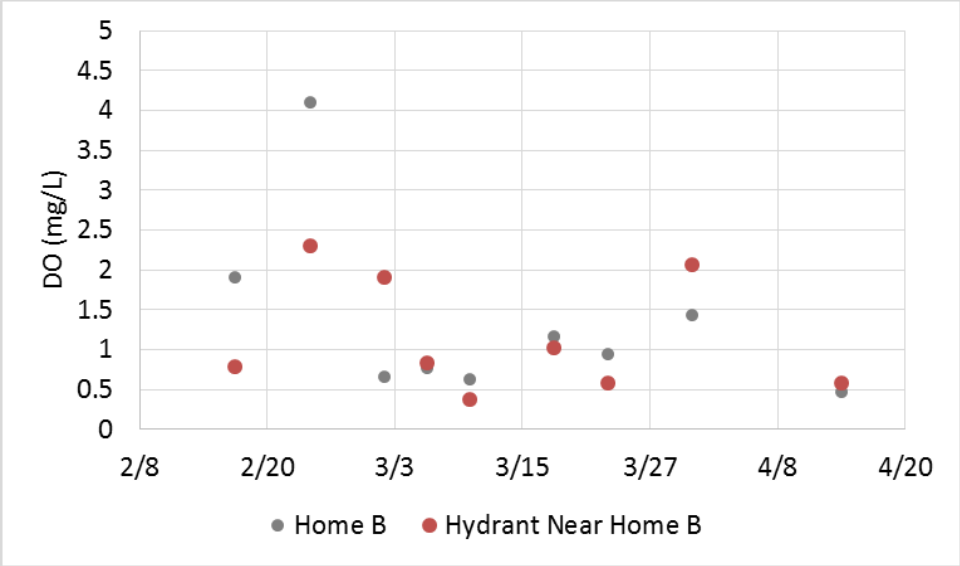

Figure 2. Routine weekly DO data for Home B.

The equipment used for this testing did not allow a specific DO level to be targeted. Operating conditions were manually adjusted in an attempt to raise DO to the target range throughout testing during the scheduled weekly visits. The equipment would have required significantly more operator attention than could be provided in order to better control DO levels.

Average water quality data for each home are presented in Figure 3.

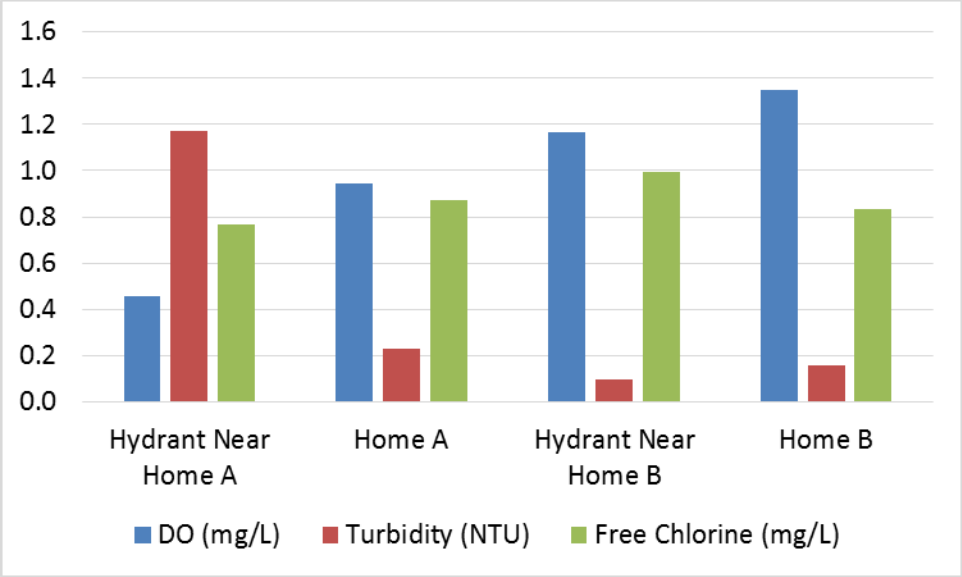

Figure 3. Average routine water quality monitoring data.

On average, DO was somewhat higher within Homes A and B compared to the distribution system, however, the increase in DO was negligible so the effect of elevated DO on in-home water quality could not be adequately assessed. Turbidity was lower in Home A compared to the distribution system, and free chlorine residuals were similar in the home compared to the hydrant for both homes. The differences between free and total chlorine residuals were found to be within 0.1 to 0.2 mg/L throughout this testing

for both homes. For Home B, average turbidity was comparable within the home as in the distribution system. Free chlorine levels were lower in the home compared to the distribution system. ORP levels averaged approximately 580 mV for Home A and 640 mV for Home B. Both homes had similar levels of ORP compared to that of the distribution system.

The average apparent color for Home A was 4.9 CU compared to 12.6 CU at the hydrant. For Home B, apparent color was found to be similar within the home and at the nearby hydrant, with average values of 2.4 CU and 1.7 CU, for the home and the hydrant, respectively.

Temperatures were found to be similar at the hose bib of each house and at the corresponding hydrant, with average temperatures for both homes of approximately 11.6°C.

Detailed Sampling Results for Home A

Data collected during detailed sampling at the homes are discussed below. In the graphs presented below, "pre-injection" refers to sampling which occurred on January 13 and 14, 2016 prior to the installation of the aeration equipment in Homes A and B, respectively. The data labeled "post-injection" refers to sampling conducted after the aeration equipment had been in operation for nearly three months, on April 26, 2016. Again, it should be noted that although the equipment had been operating, there may have been no appreciable increase in DO levels entering the home.

The difference between free and total chlorine residuals was generally less than 0.1 mg/L (suggesting that combined chlorine compounds had been oxidized within the distribution system upstream of these homes). Free chlorine residuals were similar in the distribution system pre- and post-injection (Figure 4). Post-injection chlorine residuals were consistently lower within Home A compared to the hydrant, including both aliquots collected at the cold water tap in the bathroom, all three aliquots collected at the cold water tap in the kitchen, and the hot water tap in the bathroom. Loss of free chorine residual between the sampling locations within the home and the hydrant was higher post-injection compared to pre-injection for Home A (Figure 5).

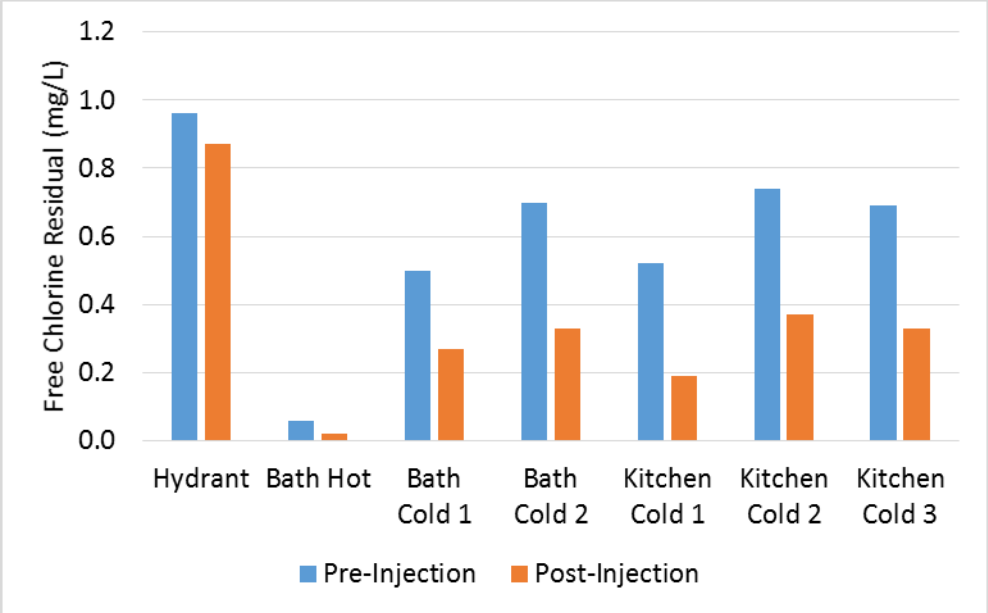

Figure 4. Free chlorine residual data for Home A.

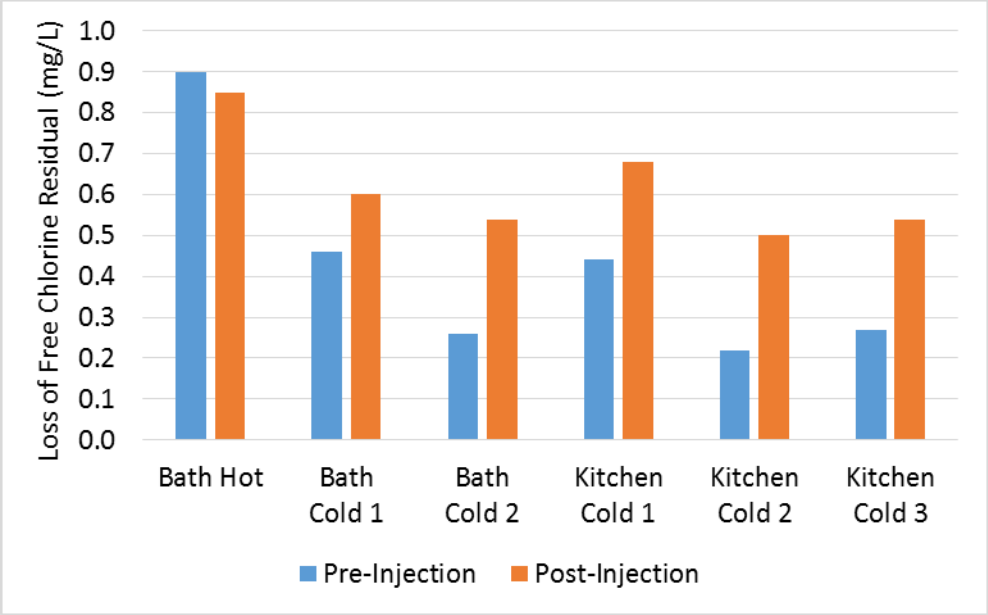

Figure 5. Chlorine residual loss data for Home A.

Pre- and post-injection turbidity levels were generally similar, with the exception of the third aliquot of water collected from the cold tap in the kitchen, which was much higher for the pre-injection sample (Figure 6).

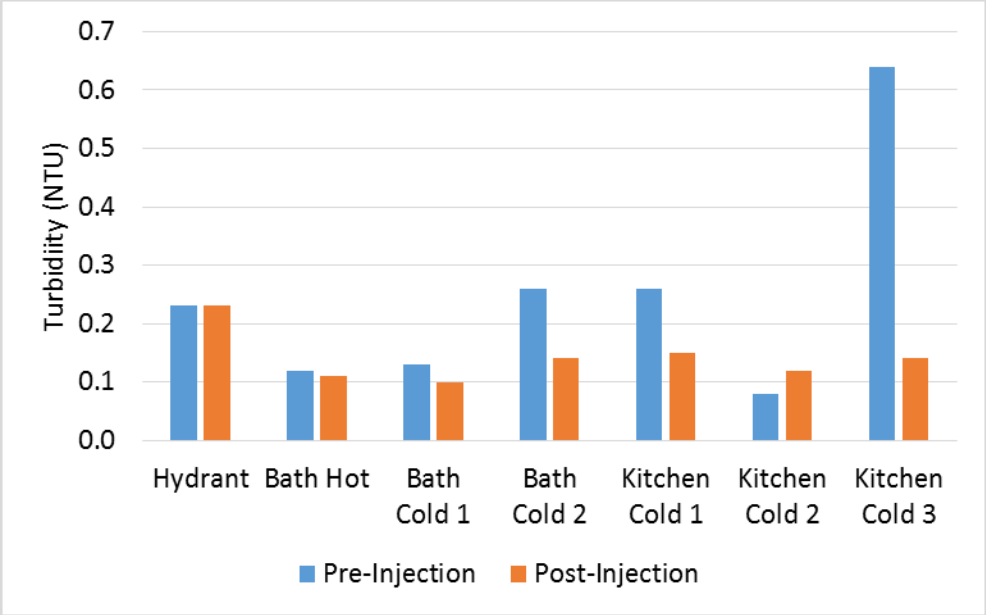

Figure 6. Turbidity data for Home A.

Distribution system levels of iron were lower post-injection compared to pre-injection (Figure 7). However, the lower levels in the distribution system did not correspond with lower levels within Home A, and iron levels were generally similar for a given sampling location within the home pre- and post-injection, with the exception of the cold water kitchen tap which had elevated iron prior to the pilot test (corresponding with elevated turbidity and apparent color in that sample).

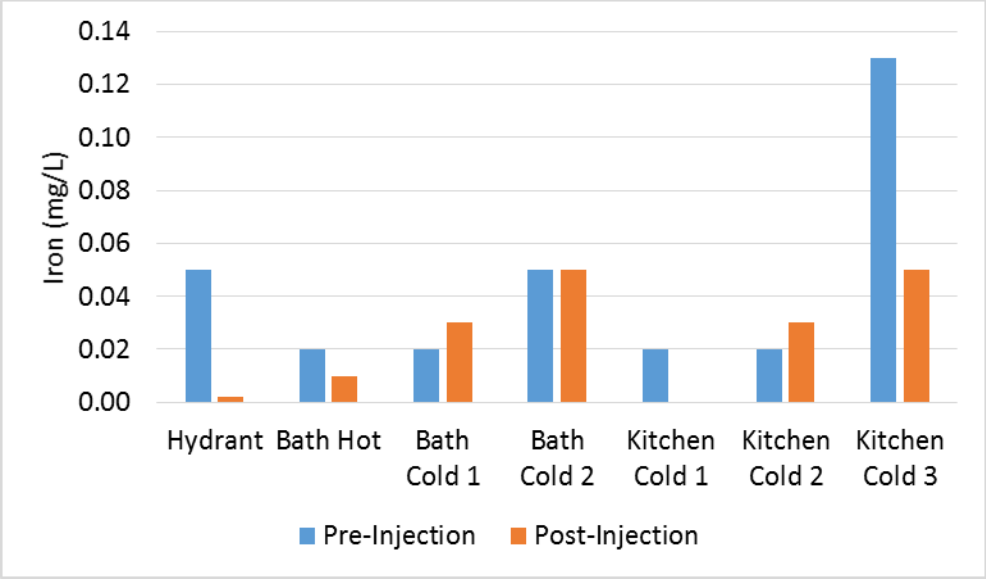

Figure 7. Iron data for Home A.

Apparent color levels in the distribution system also decreased between pre- and post-injection (Figure 8). Apparent color levels in Home A appeared to improve over the duration of this trial, with most samples below the method detection limit for post-injection sampling.

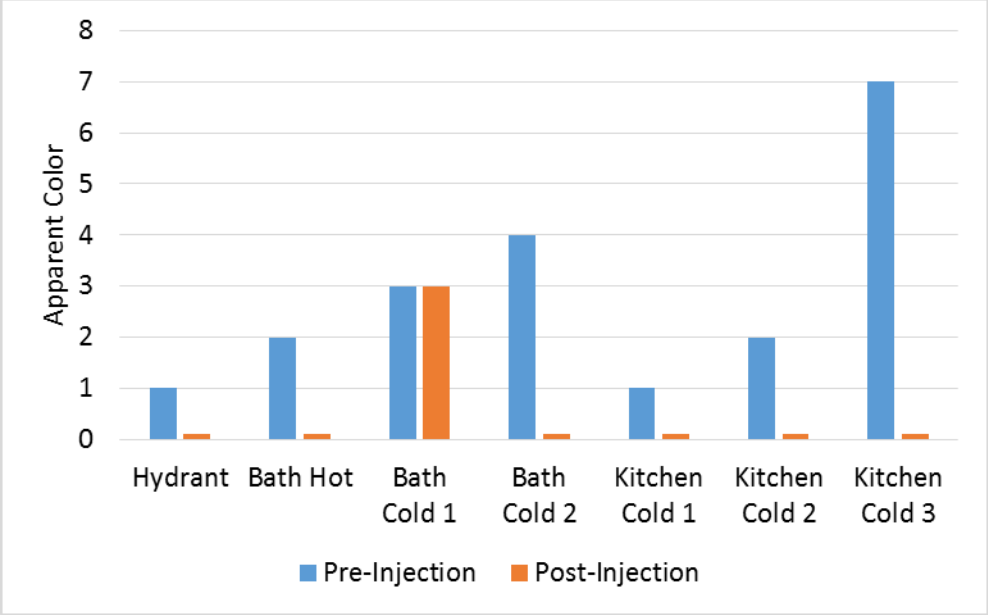

Figure 8. Apparent color data for Home A.

ATP levels were consistently low for Home A both pre- and post-injection, with the exception of the bathroom hot water tap, for which ATP levels were somewhat elevated at the end of the DO trial (Figure 9). ATP levels within the homes were strongly influenced by chlorine levels, as shown in Figure 10 for Home A. According to the ATP method manufacturer, ATP levels less than 0.5 pg/mL are considered low and indicate good microbial control in drinking water. Levels between 0.5 - 10 pg/mL suggest a review of preventative strategies. Levels greater than 10 pg/mL indicate the need for corrective action.

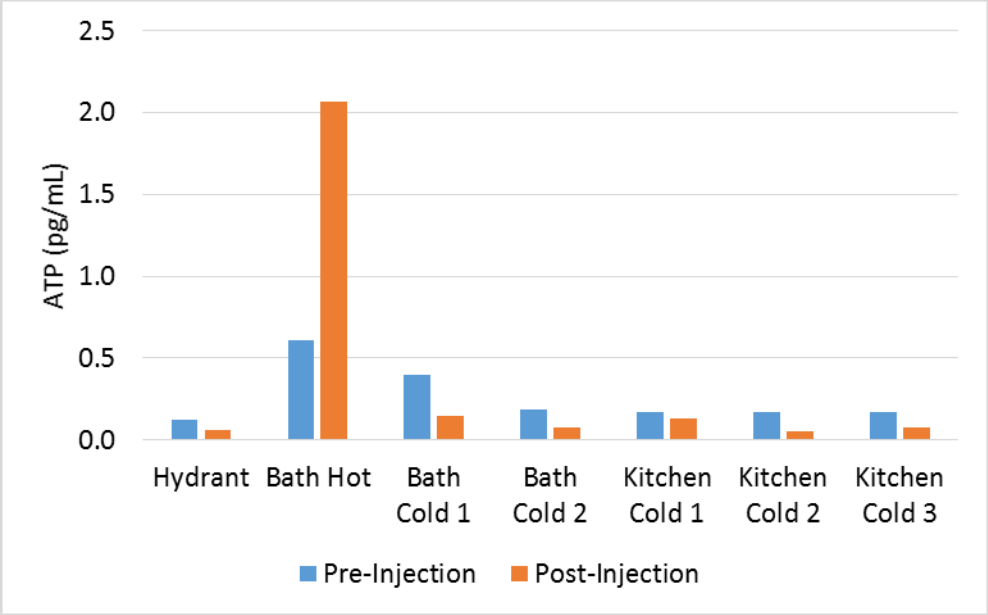

Figure 9. ATP data for Home A.

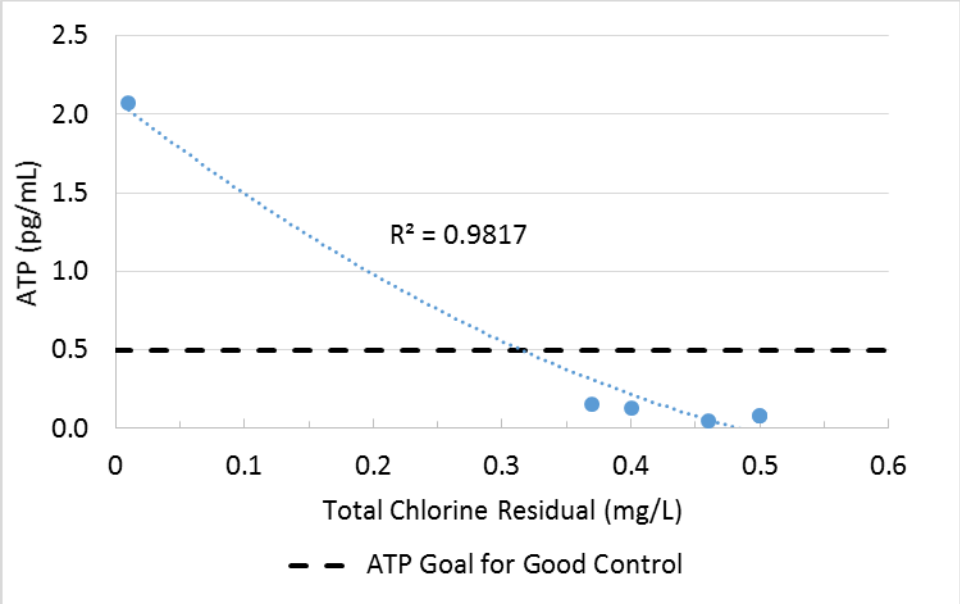

Figure 10. Total chlorine vs. ATP for Home A.

Taste and odor were likely controlled by conditions in the distribution system for Home A, rather than water quality conditions within premise plumbing. Post-injection FRA levels for samples collected in the home were similar to distribution system levels with little variation among the sampling locations (Figure 11). Since chlorine was largely responsible for pre-injection objectionable odors in the distribution system sample, dissipation of chlorine residuals within the home likely contributed to an improvement in taste and odor characteristics. Sulfur and pencil odors were noted in the kitchen cold water tap and bathroom hot water tap samples collected post-injection.

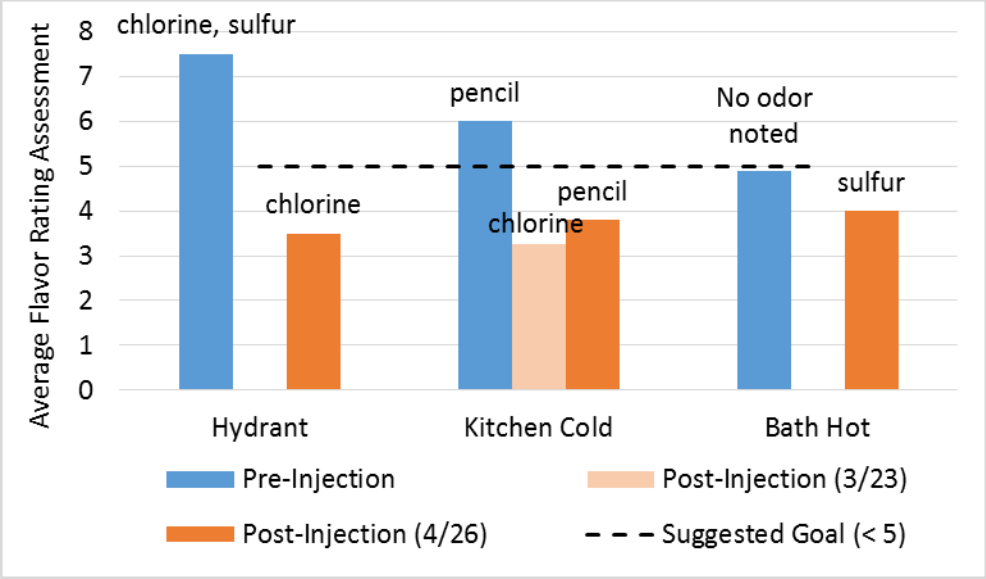

Figure 11. Taste and odor data for Home A.

Sulfides were not detected in any of the detailed analytical sampling conducted at Home A, despite sulfurous odors noted in the FRA. Manganese results varied between 0.02 and 0.03 mg/L with similar results obtained at the hydrant and within Home A. The pH at the hydrant varied from 7.6 to 7.8 and similar pH levels were observed within Home A. The temperature of the water at the kitchen and bathroom cold water tap within Home A decreased as a function of aliquot number, as expected, as colder water was drawn into the home from the service line.

Detailed Sampling Results for Home B

The difference between free and total chlorine residuals was consistently less than 0.1 mg/L for Home B. Free chlorine residuals were lower in the distribution system post-injection compared to pre-injection (Figure 12).

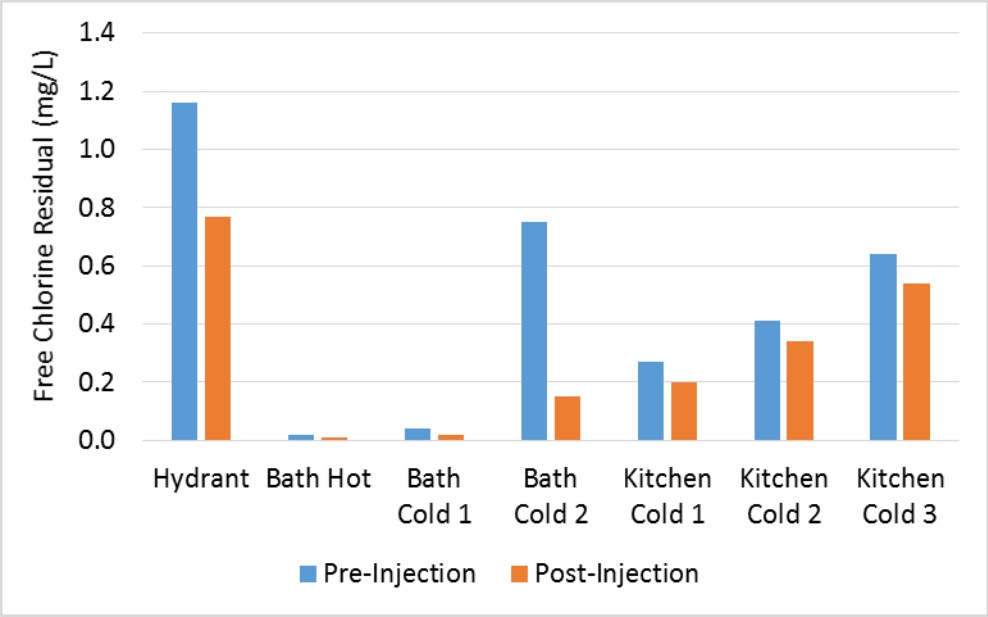

Figure 12. Free chlorine data for Home B.

Post-injection free chlorine residuals were correspondingly lower at all sample locations within Home B compared to pre-injection. Post-injection loss of free chorine residual between the sampling locations within the home and the hydrant were lower compared to pre-injection for Home B (Figure 13).

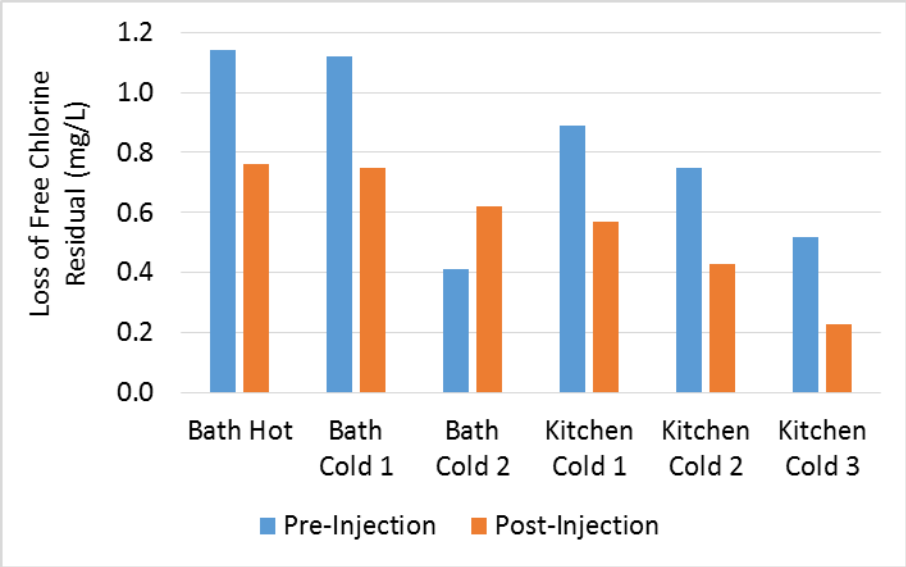

Figure 13. Chlorine residual loss data for Home B.

Similar (and relatively low) levels of turbidity and iron were observed in the distribution system during sampling conducted pre- and post-injection (Figures 14 and 15, respectively). Turbidity and iron had similar patterns within Home B, with lower levels of both parameters occurring post-injection.

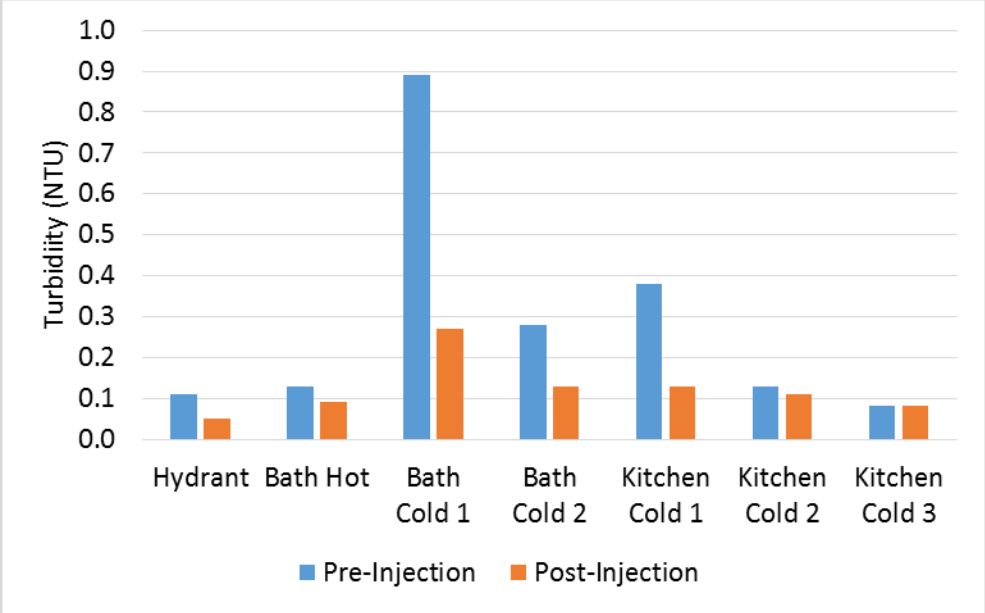

Figure 14. Turbidity data for Home B.

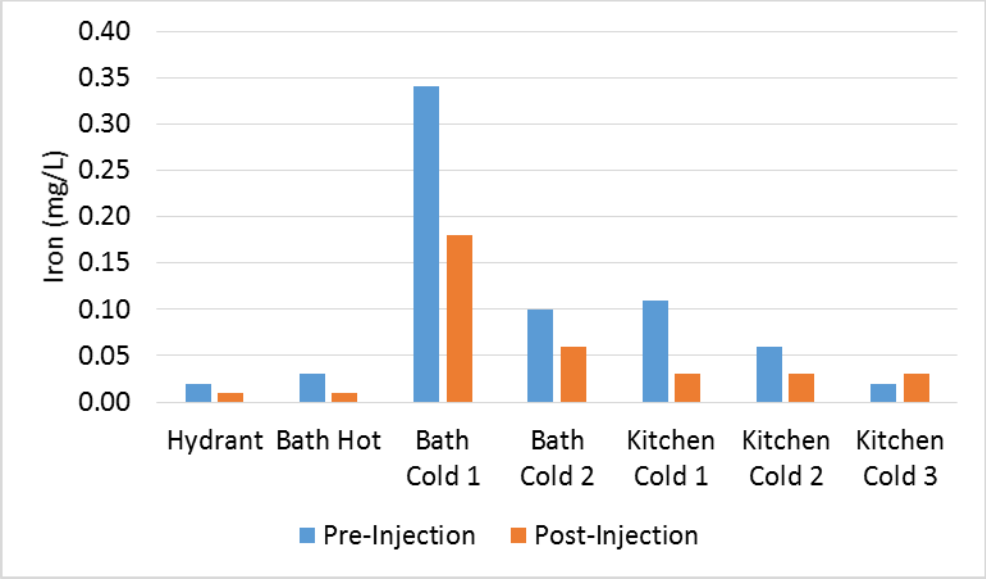

Figure 15. Iron data for Home B.

Apparent color also consistently improved post-injection, however, the apparent color level in Home B was likely affected by conditions within the distribution system, with significantly lower levels of apparent color occurring for the post-injection sampling, compared to pre-injection (Figure 16).

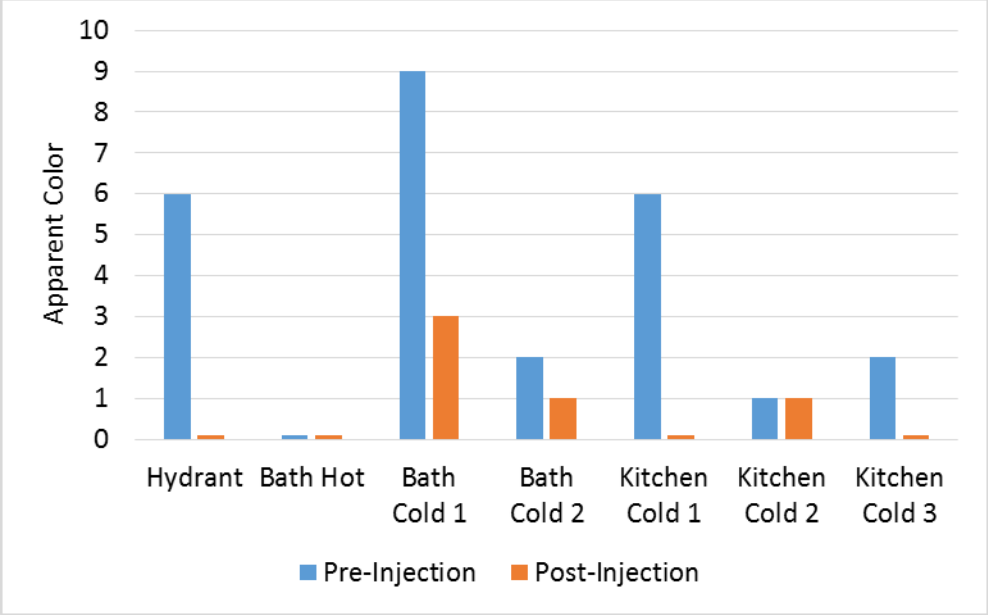

Figure 16. Apparent color data for Home B.

Post-injection ATP levels were lower at the cold water taps in the bathroom and kitchen compared to pre-injection (Figure 17). The post-injection hot water tap had slightly higher levels of ATP compared to pre-injection for Home B. As with Home A, ATP was strongly influenced by chlorine levels (data not presented).

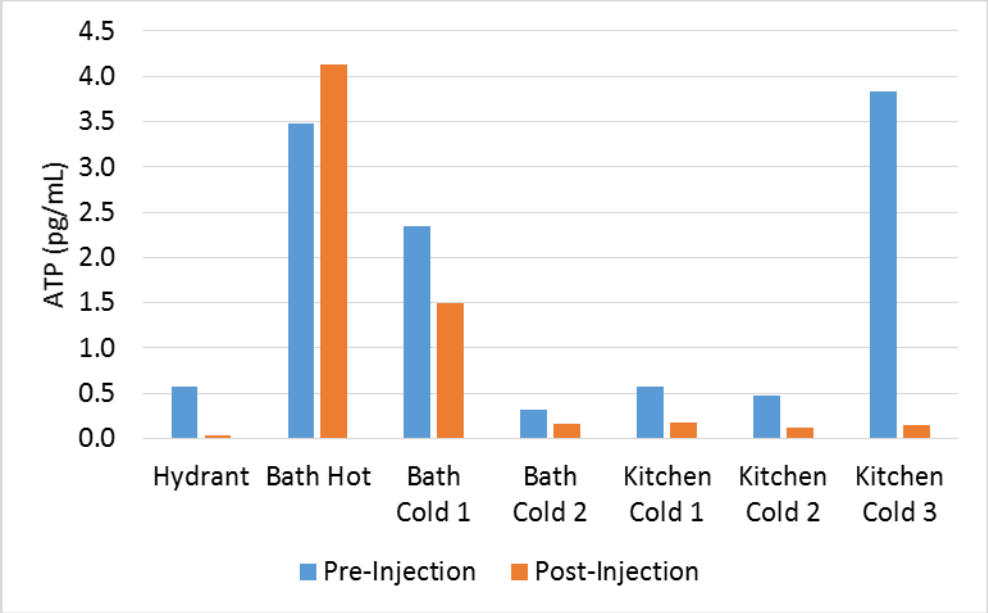

Figure 17. ATP data for Home B.

Taste and odor appeared to improve post-injection compared to pre-injection, however, it is likely that taste and odor characteristics were more affected by distribution system conditions than water quality conditions within premise plumbing. An objectionable level of chlorine and sulfur odors was observed at the hydrant near Home B pre-injection (Figure 18). Mineral and pencil odors occurred within Home B during pre-injection sampling. Taste and odor characteristics had improved significantly within the distribution system three months later, during post-injection sampling, with similar levels of taste and odor within Home B as measured in the distribution system.

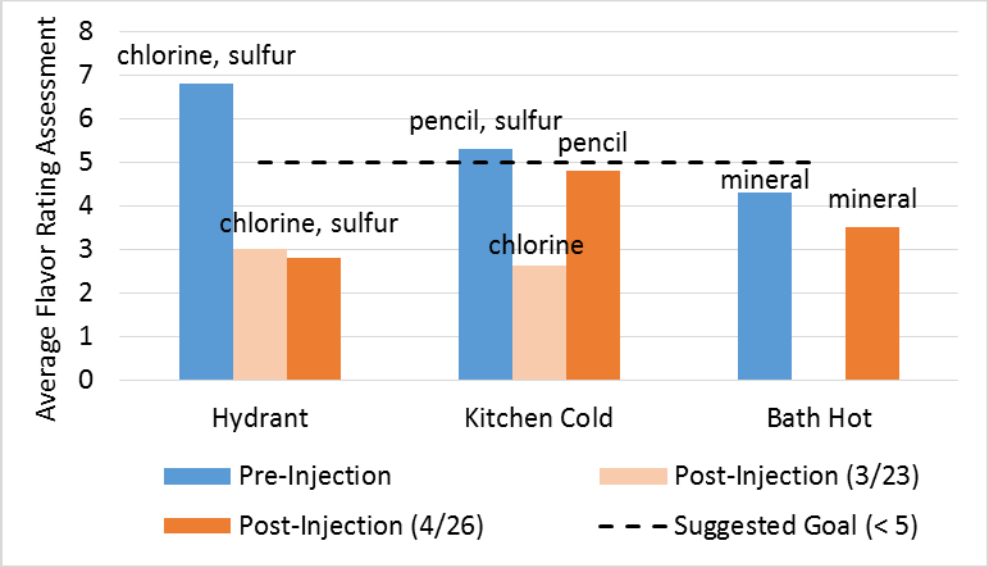

Figure 18. Taste and odor data for Home B.

Sulfides were not detected in any of the detailed analytical sampling conducted at Home B, despite sulfurous odors noted in the FRA. Manganese results varied between 0.02 and 0.05 mg/L with similar results obtained at the hydrant and within Home B. The pH at the hydrant varied from 7.6 to 7.8 and similar pH

levels were observed within Home B. The temperature of the water at the kitchen and bathroom cold water taps within Home B decreased as a function of aliquot number, as expected, as colder water was drawn into the home from the service line.

Conclusions

The benefits of elevated DO have been demonstrated in previous pipe rig testing at the MFRWTP, including lower levels of iron, manganese, and color for unlined cast iron pipe, however, additional benefits of improved water quality within home plumbing using premise aeration, could not be demonstrated during this pilot test. The aeration equipment used did not provide the desired increase in DO. DO levels within the two homes included in this test appeared to remain well below the target range of 4 to 8 mg/L throughout the majority of testing. Since only a negligible increase in DO was actually achieved, any improvement in water quality may be attributable to other factors, such as changing water quality conditions in the distribution system.

Given that the target range of DO within each home was not achieved, definitive conclusions cannot be drawn. Potential trends observed from the data that were collected are as follows:

- Slightly increased DO levels may have contributed to lower levels of turbidity, iron, and apparent color within both homes included in this test.
- Slightly elevated DO did not stabilize free chlorine residuals in Home A, but may have contributed to lower chlorine loss in Home B.
- ATP levels were strongly influenced by chlorine levels within both homes. It is unclear if DO had any impact on ATP levels.
- Lower levels of taste and odor within the homes observed post-injection corresponded to lower levels of taste and odor in the distribution system samples for both homes. Chlorine and sulfur odors within the homes were lower compared to the distribution system in pre-injection samples. Taste and odor characteristics were similar in the distribution system compared to within the homes during post-injection sampling.
- Chlorine residuals were found to be lower within the homes compared to distribution system water. Also the homes had higher levels of iron and turbidity compared to the distribution system, suggesting the accumulation of sediments and biofilm within the home, and that these accumulated constituents are hydraulically mobile.

Recommendations

- Microbial activity is higher in hot water plumbing compared to the cold water side. Homeowners should be provided with instructions for draining and cleaning hot water tanks and changing anodes, as appropriate, to minimize the development of sulfurous odors.
- If the MFRWTP is to be used as the long-term supply for the City, additional DO testing should be considered. The City should consider additional pilot studies or a larger scale demonstration study of the effects of elevated DO in the finished water, on water quality in the distribution system. The benefits of DO for lowering iron release from pipe scales and for lowering the development of hydrogen sulfide are documented in the literature and water quality improvements for unlined cast iron pipe were demonstrated during previous pipe rig testing at the MFRWTP.
- Water quality conditions within the homes would likely be improved by implementation of an aggressive whole-house flush. Such flushing would purge hydraulically mobile sediments from the home. Instructions for verifying service line materials and for conducting the flushing to maximize

performance and minimize unintended consequences should be provided prior to implementation.