FINAL

WATER QUALITY EVALUATION

Technical Memorandum

B&V PROJECT NO. 406304

REGISTERED PROFESSIONAL ENGINEER
ASHUTOSH S. SHIROLKAR
No.C069603
CIVIL
STATE OF CALIFORNIA

PREPARED FOR

CITY OF
FOLSOM
DISTINCTIVE BY NATURE

City of Folsom

OCTOBER 16, 2020

BLACK & VEATCH

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1.0 Executive Summary

The City of Folsom (City) began experiencing pin hole leaks in copper piping at residential and business locations throughout the distribution system in July 2020. The sudden onset and frequency of pin hole leaks caused the City to reach out to Black & Veatch for help identifying the cause of the problem and to understand potential solutions that the City could undertake if water quality was determined to be a contributing factor for the pin hole leaks. This evaluation included both a review of historical water quality and pipe scale analysis of harvested copper pipes with pin hole leaks.

The City has produced a high-quality potable water that under most circumstances provided the optimal corrosion control treatment as demonstrated by historical compliance with the Lead and Copper Rule (LCR). The City's record of compliance regarding the low levels of lead and copper detected during LCR compliance monitoring since the rule was promulgated in 1991 has allowed the City to qualify for triennial sampling. The California State Water Resources Control Board, Division of Drinking Water (DDW) approved of the City's corrosion control treatment.

The source water that the City treats contains low levels of alkalinity (i.e., less than 40 mg/L as $CaCO_3$ or calcium carbonate), calcium, total organic carbon (1 mg/L), total dissolved solids, turbidity, etc., which is desirable to customers. However, the purity of this water source combined with a pH above 9 and free chlorine for disinfection could contribute to pitting in copper pipe, especially at sites with impurities in the pipe material or at sites where particulate settled. Pipe scale analysis validated this conclusion. Impurities in copper pipes are natural and could be from manufacturing like microscopic burrs, ions other than copper included in the metal, or remnants of cleaning solutions. Storage, transportation, installation, and soldering could all introduce additional impurities, but research studies have shown that while impurities can provide a site to start pitting, their presence is not necessary for pitting to occur in all situations.

Research studies have been able to replicate pitting corrosion on copper pipes using waters with pH above 9, low alkalinity (<40 mg/L as $CaCO_3$), and free chlorine; and the most reliable solution used the addition of orthophosphate to hinder the pitting corrosion [1, 2]. Orthophosphate has been used successfully by some Utilities across the United States to limit pitting and pin hole leaks in copper pipes [2, 1]; however, not all Utilities have used or are using orthophosphate, and adding orthophosphate does not guarantee pitting and pin hole leaks will not occur.

Due to the urgency on the City's part to diagnose the cause of copper pin hole leaks and, if available, implement a water quality solution quickly, it appears that orthophosphate is the most proven solution. It was recommended that the City consult DDW to determine the necessary steps to begin feeding orthophosphate. On September 18, 2020 the City consulted DDW, and on September 30, 2020, the City received a letter from DDW that granted temporary authorization for emergency operation of orthophosphate treatment process.

The City consulted Black & Veatch on where to place the chemical feed, what type of dosages should be targeted, as well as monitoring that should be completed. The City is moving forward with adding orthophosphate to the treated water following requirements from DDW's approval letter as well as the dosage and monitoring recommendations from Black & Veatch. The selected orthophosphate chemical is a commonly used corrosion inhibitor that is recommended by the United States Environmental Protection Agency for use in drinking water applications and is deemed safe for drinking water systems by the United States Food and Drug Administration. The addition of orthophosphate should begin to form a protective layer on the interior pipe surfaces to limit further pitting corrosion. The appearance of the City's water should remain the same with the addition of orthophosphate.

2.0 Introduction

The City of Folsom (City) began experiencing pin hole leaks in copper piping at residential and business locations throughout the distribution system in July of 2020. The sudden onset and frequency of pin hole leaks caused the City to reach out to Black & Veatch for help identifying the cause of the problem and to understand potential solutions that the City could undertake if water quality was determined to be a contributing factor for the pin hole leaks. Black & Veatch began its analysis in August 2020.

This evaluation included both a review of historical water quality and pipe scale analysis of harvested copper pipes with pin hole leaks. This combination of analyses allowed for historical trends in finished water quality to be reviewed and compared with water quality in the distribution system to determine potential causes for the pin hole leaks, while forensic analysis of pipe materials and existing pipe scale was used to verify or rule out potential causes of pin hole leaks. The analysis of pipe scale on harvested copper pipes was conducted by Dr. Marc Edwards and Dr. Jeffrey Parks at Virginia Tech.

3.0 Lead and Copper Rule Compliance Results

Since the Lead and Copper Rule (LCR) was promulgated in 1991, the City has measured lead and copper values well below the respective action levels. Due to the low levels of lead and copper detected, the City qualified for triennial monitoring with the California State Water Resources Control Board, Division of Drinking Water (DDW). The City has demonstrated limited metal leaching from premise plumbing and service line materials by historical compliance with the LCR.

The City does not have any known lead service lines in its distribution system. The sources of lead are typically within premise plumbing as lead solder or brass fixtures or fittings even if they were labeled “lead free”. The Safe Drinking Water Act (SDWA) specifies that any pipe, fitting, fixture, or solder used after June 1986 be “lead-free.” At that time, “lead-free” was defined as having less than 8 percent lead content. In 2014, the lead content was further reduced to not containing more than 0.2 percent lead when used with respect to solder and flux, and not more than a weighted average of 0.25 percent lead when used with respect to the wetted surfaces of pipes, pipe fittings, plumbing fittings, and fixtures.

Homes that met these criteria (i.e., contained copper pipe with lead solder) were selected by the City and approved by DDW for LCR compliance monitoring to capture potential lead and copper leaching. The City is currently required to monitor for lead and copper at 30 sites for each round of testing. In practice, the City typically goes above that requirement and samples at nearly double the number of sites to ensure that they are providing the highest water quality to its customers.

Both the 2017 and 2020 LCR monitoring periods resulted in non-detect levels of copper as shown in Figure 1. Figure 1 displays the 90th percentile value for which compliance is based on with respect to the copper action level of 1.3 mg/L for each round of LCR monitoring.

The 90th percentile value for lead has been non-detect and well below the lead action level of 0.015 mg/L since 2011 as demonstrated in Figure 2.

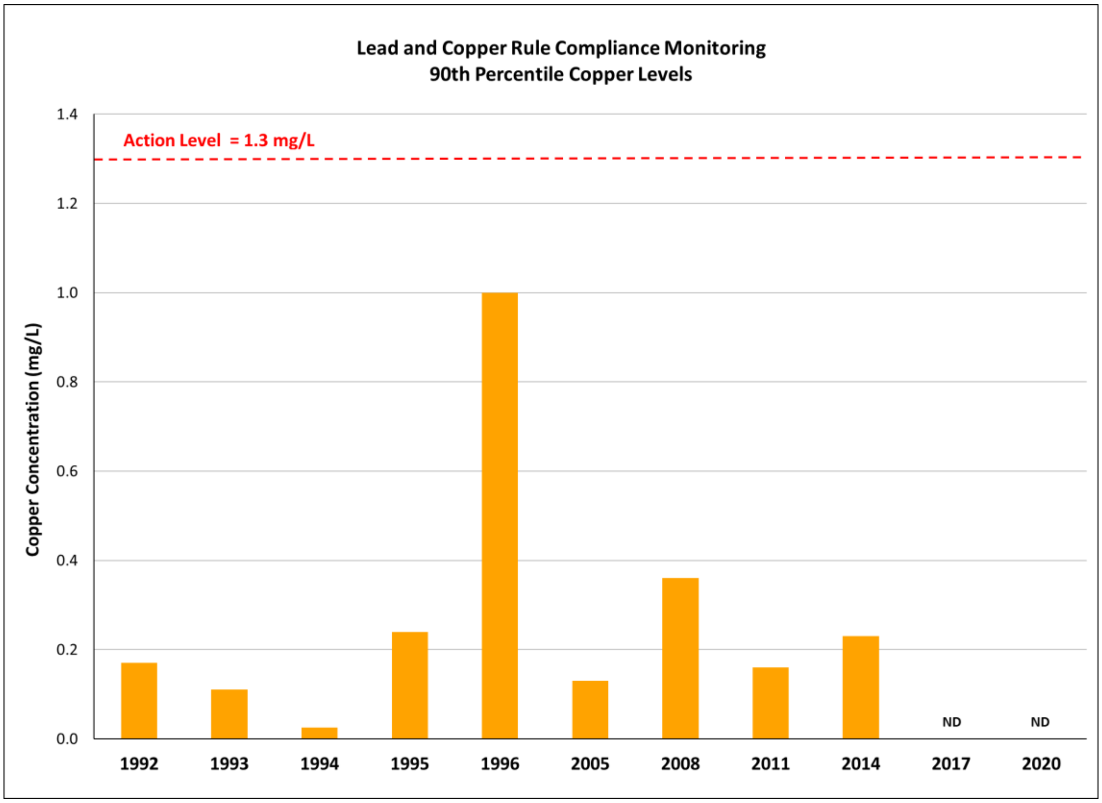

Figure 1: 90th Percentile Copper Results from LCR Monitoring

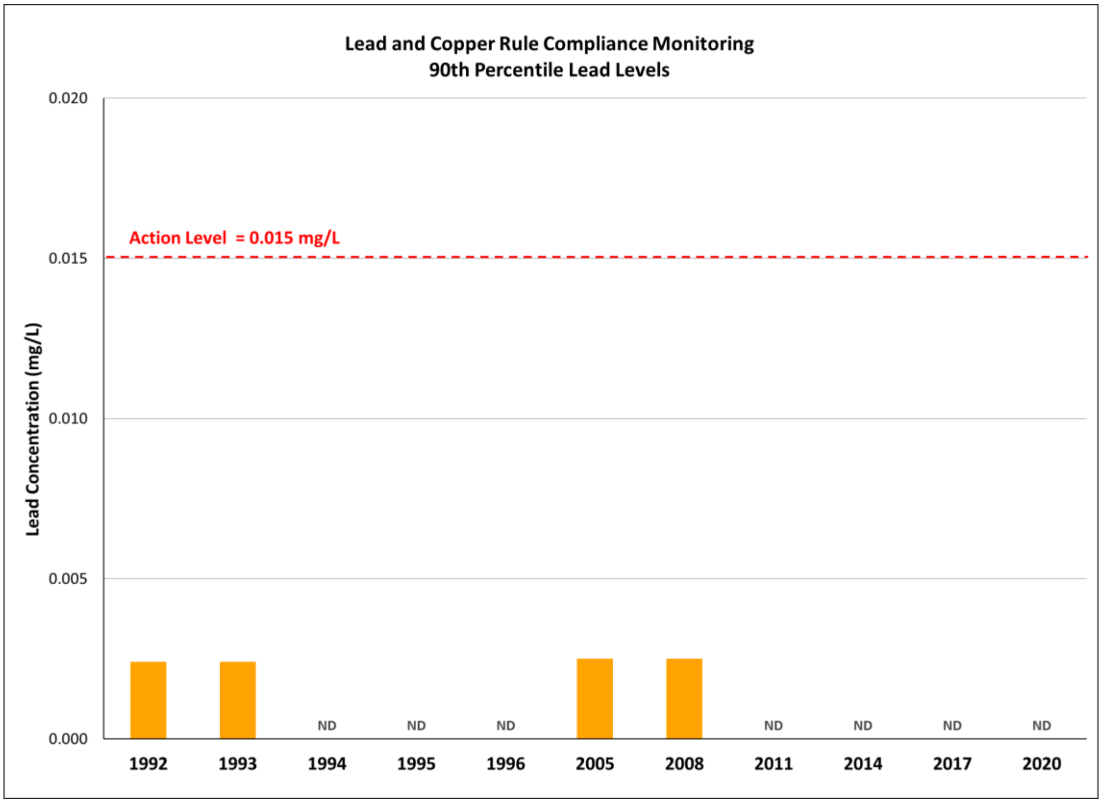

Figure 2: 90th Percentile Lead Results from LCR Monitoring

4.0 Water Quality Analysis

The City's water source is snow melt and precipitation runoff collected in the Folsom Reservoir. The raw water is purified through a conventional water treatment plant (WTP) that is rated to produce 50 million gallons per day (mgd). The WTP facilities divide the raw water flow between a 15 mgd conventional flocculation sedimentation basin and two 20 mgd Actiflo® high rate clarification units. At the head of each pretreatment facility, aluminum chlorohydrate (ACH) is added as a coagulant. The water is further treated using sand/anthracite dual media filters for particle removal. Sodium hypochlorite is added for disinfection at the influent to the chlorine contact tank (CCT). The last step in the treatment process is addition of calcium hydroxide (lime) downstream of the CCT as a means of adjusting pH based on the Langelier Saturation Index (LSI) for corrosion control.

Finished water quality at the entry point to the distribution system was evaluated for several key water quality parameters and the overview of that analysis is detailed in Table 1. The pH data is from online analyzers linked to SCADA, while the other parameters are from grab samples, which are samples of water collected by hand and then analyzed with field equipment or taken to a laboratory for analysis. The chlorine residual data were collected at the Tower Reservoir (located near the entry point to the distribution system) as the entry point grab sample data did not include this parameter for historical samples. Table 1 also includes a calculated corrosion indicator to quantify the aggressiveness of the finished water.

Table 1: Finished Water Quality at the Entry Point to the Distribution System

ANALYTE	UNITS	MIN	5TH PERCENTILE	AVERAGE	95TH PERCENTILE	MAX	SECONDARY MCL
pH [1]	Standard units	6.1	7.1	8.2	9.2	10.45	6.5-8.5
Alkalinity [2]	mg/L as $CaCO_3$	18	18	25	34	35	–
Hardness [2]	mg/L as $CaCO_3$	12	17	23	31	33	–
Total Dissolved Solids (TDS) [2]	mg/L	24	34	47	59	70	500
Calcium [2]	mg/L	3.5	4.6	6.3	8.3	9.3	–
Magnesium [2]	mg/L	1.1	1.1	2.0	3.0	4.8	–
Chloride [2]	mg/L	3.3	3.5	5.3	9.2	9.9	250
Sulfate [2]	mg/L	0.5	1.1	2.3	3.5	11	250
Chlorine Residual [4]	mg/L Cl_2	0.1	0.8	1.1	1.5	2.0	MRDL: 4.0
Total Organic Carbon, TOC [2]	mg/L	0.6	0.7	1.0	1.5	1.8	–
Calculated Corrosion Indicator							
Langelier Saturation Index, LSI [3]		-2.3	-2.1	-1.2	-0.3	-0.2	Noncorrosive

Secondary MCL: Secondary Maximum Contaminant Level (These are non-enforceable guidelines regulating contaminants that may cause cosmetic effects or aesthetic effects in drinking water)

MRDL: Maximum Residual Disinfectant Level

[1] Data collected from online analyzers from 2016-2020

[2] Data collected from select grab samples from 2010-2020

[3] Data collected from select grab samples from 2016-2020

[4] Data collected from daily log sheets 2010-2020 at Tower Reservoir (located near entry point in the distribution system)

The key findings from the entry point data analysis include the following:

- Over a five-year span the hourly pH ranged from a low of 6 to a high of 10 but was typically in the 8.0-9.0 range on a daily basis, and a pH above 9 can potentially influence corrosive conditions.
- The source water is very pure as confirmed by low levels of alkalinity, calcium, hardness, total dissolved solids, etc.
- The water has limited buffering capacity due to the low levels of alkalinity. Buffering capacity describes the water's ability to resist changes in pH when an acid or base are added. A small concentration of lime can increase the pH of the City's water, whereas a water with high alkalinity (i.e., high buffering capacity) would require a higher dosage of lime to raise the pH. The low alkalinity of the City's water makes it more responsive to changes in chemical dosages and requires additional monitoring, which the City performs using continuous online pH analyzers.
- Due to the low organic content of the finished water (1 mg/L of TOC), a chlorine concentration of approximately 1 mg/L Cl_2 leaving the WTP is sufficient to maintain a residual throughout the distribution system.
- While typical of low alkalinity (i.e., <40 mg/L as $CaCO_3$) snowmelt waters in the Pacific Northwest, the Langelier Saturation Index (LSI) indicates that the water could have naturally corrosive tendencies due to its lack of minerals from the purity of the source.

LSI is a corrosion indicator calculated by most WTPs and is often used to adjust finished water quality parameters to maintain a target value. LSI is determined using a calculation that includes pH, alkalinity, calcium, total dissolved solids (TDS), and temperature. The City's pure water source was analyzed for TDS and calcium monthly and those values were used as inputs along with online measurements or daily grab samples of pH, alkalinity and temperature. Due to the purity of the City's source water, the alkalinity, calcium and TDS are very low, which results in a negative LSI.

A negative LSI indicates that the water is deficient in minerals and could be aggressive towards metallic pipe materials and cement linings of tanks and pipes as the water will try to extract minerals and metals to achieve equilibrium. A positive LSI indicates that the water is over-saturated with minerals and as such these minerals will likely precipitate out in the form of calcium carbonate or other compounds as the water tries to reach equilibrium. A neutral LSI in the range of -0.5 to 0.5 indicates that the water is stable and will neither precipitate nor leach minerals.

The City adds lime at the WTP to increase pH, alkalinity, and calcium. Due to the purity of the raw water, the City typically operates with a negative LSI in the range of -1.4 to -1.7 even after the increase in these three parameters. The City has maintained the strategy of adjusting the lime dose to target a finished water pH, while keeping the LSI from decreasing further. This approach has historically been successful as a corrosion control strategy as indicated by the low levels or lead and copper observed in LCR monitoring, and it has been approved by DDW. Unfortunately, as discussed in later sections and in Appendix A and Appendix C, the increase in pH over the last few years, along with impurities in the pipe materials or settled particulate, can potentially contribute to pin hole leaks. If pH was maintained at 8.5 there may be slight changes in LSI seasonally as temperature changes, or slight variations as a result of slight changes in alkalinity, calcium or TDS, but LSI would probably remain in the -1.0 to -2.0 range, which would not change the waters aggressiveness towards cement linings.

Historical data were reviewed temporally to gather insight into any trends in water quality that could be associated with pitting corrosion in copper pipes. Finished water pH is a critical parameter that has changed since 2016 as shown in Figure 3. Additionally, raw source water pH data were included in Figure 3 to display the difference between raw water pH and treated water pH. All pH measurements were collected hourly.

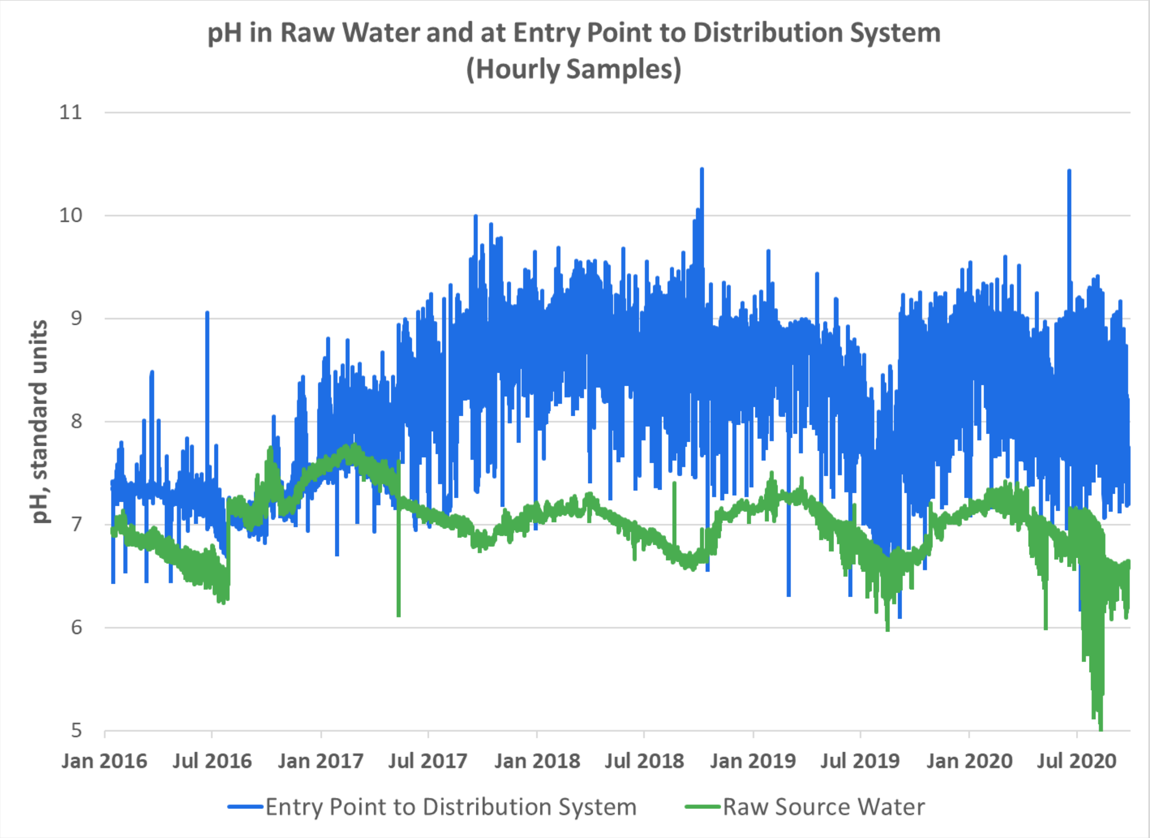

Figure 3: pH Measured Hourly at the Entry Point to the Distribution System and in the Source Water

pH in the raw source water displays seasonal fluctuations with the pH dropping slightly in summer and fall when the water temperatures increase and biological activity increases. These trends can be observed in the treated water at the entry point. Additional lime would be necessary in the summer and fall to keep a consistent pH, which would result in a higher LSI value (a less negative number).

pH at the entry point showed little variability during 2016, but then in 2017 the entry point pH starts increasing and the daily fluctuations in pH become more pronounced. The average daily fluctuation in pH measured at the high service pump station at the entry point to the distribution system was 0.24 pH units in 2016 and has been 0.76 pH units from 2017 through 2020. These daily fluctuations in pH based on hourly measurements by online analyzers is evident in Figure 3.

Since mid-2017 the pH at the entry point has been centered around 8.5, with variations spanning from nearly a low of 6 to a high of 10 and an observable dip in finished water pH in the summer of 2019 when the entry point pH was typically 7.0 to 7.5. The variability in finished water pH is partially due to the low alkalinity and limited buffering capacity for the treated water, but also due to changes in the approach for meeting finished water targets. The low buffering capacity of the City's water makes it more responsive (i.e., bigger fluctuations in pH) to changes in the lime dosage or a change in flow at the lime feed point due to water being used for a filter backwash.

The United States Environmental Protection Agency (US EPA) recommends avoiding a pH change greater than 0.3 pH units whenever pH adjustments are made in the Optimal Corrosion Control Treatment Technical Manual [3]. Using LSI as a target for corrosion control in a system like the City's where the water has little buffering capacity can be difficult. It is more important to target a pH value than to target an LSI value as pH is the master variable that affects all reactions within the bulk water and between the water and distribution system materials.

The pin hole leaks have mostly been observed in Zone 1, Zone 2 and Zone 3 of the City's distribution system. A map of the City's system with pressure zone designations is shown in Figure 4. Three separate graphs were developed to display changes in pH from the entry point to the main reservoirs that serve each of these pressure zones. Figure 5 shows the average daily pH at the entry point and the daily grab sample pH from the South Reservoir in Zone 1. Figure 6 shows the average daily pH at the entry point and daily grab sample pH from both the East Reservoir and the Tower Reservoir in Zone 2. Figure 7 shows the average daily pH at the entry point and the daily grab sample pH from the Cimmaron Reservoir in Zone 3.

Daily pH data collected in the distribution system were higher than the daily average pH in the finished water at the entry point in 2019 and 2020 as seen in Figure 5, Figure 6, and Figure 7. pH can change as the water travels through miles of pipes and interacts with the pipe surfaces and reservoirs. In some distribution system reservoirs, undissolved lime can settle out, which could alter the pH within the distribution system. Other causes for pH fluctuations are related to microbial growth in the distribution system, which has been ruled out as a cause for the City's copper pitting, and the degradation of chlorine residual as well as corrosive conditions and extended water age.

The more likely explanation for the City's system is that the pH reading at the entry point is too close to the lime feed point and the water is still reacting to the chemical addition due to the low buffering capacity. Additional monitoring is recommended to validate this theory, since the pH values measured in the distribution system, especially in Zone 1, are often different from the daily average pH values at the entry point by more than 0.5 pH units.

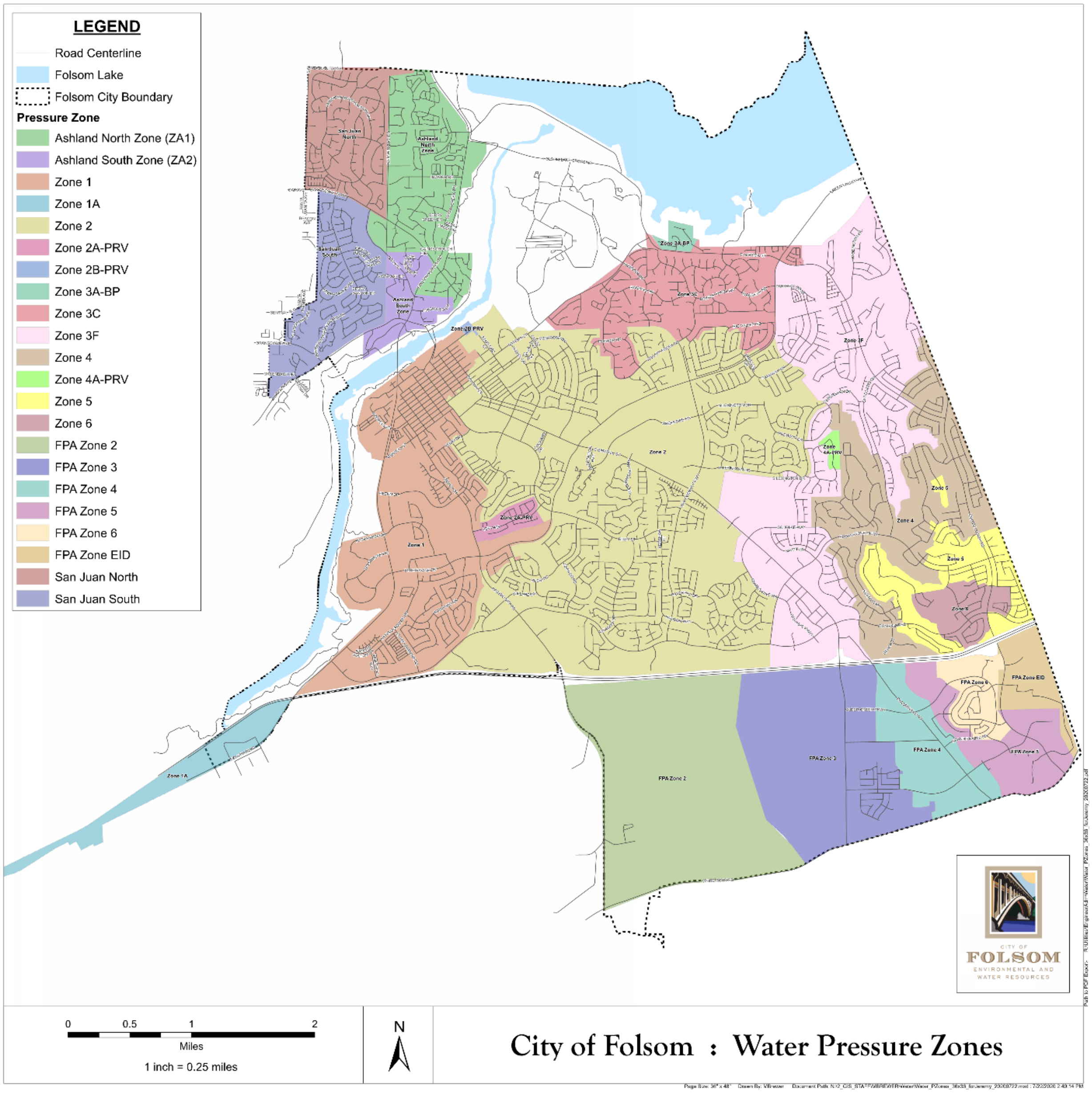

Figure 4: Map of the City's Pressure Zones in the Distribution System

The pH exceeded 9.0 in Zone 1 of the distribution system in the fall of 2018 as seen in Figure 5. The same results were seen in Zone 2 and Zone 3 of the distribution system as displayed in Figure 6 and Figure 7, respectively.

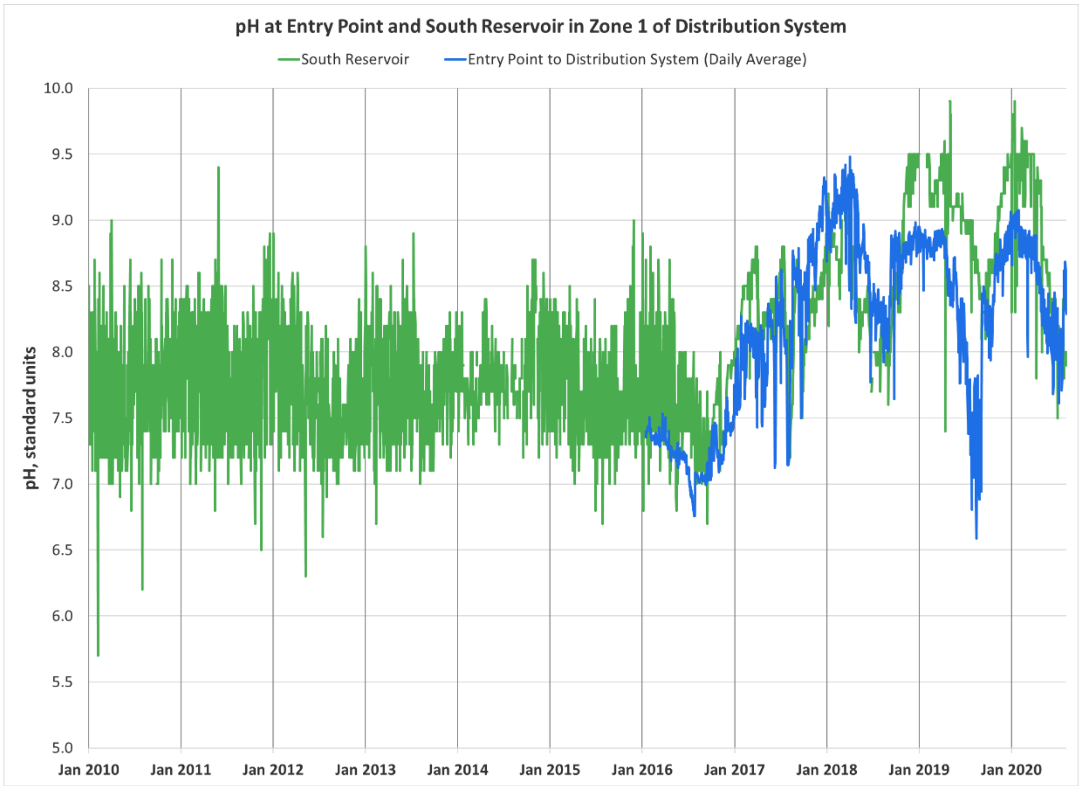

Figure 5: pH at Entry Point and Zone 1 (South Reservoir)

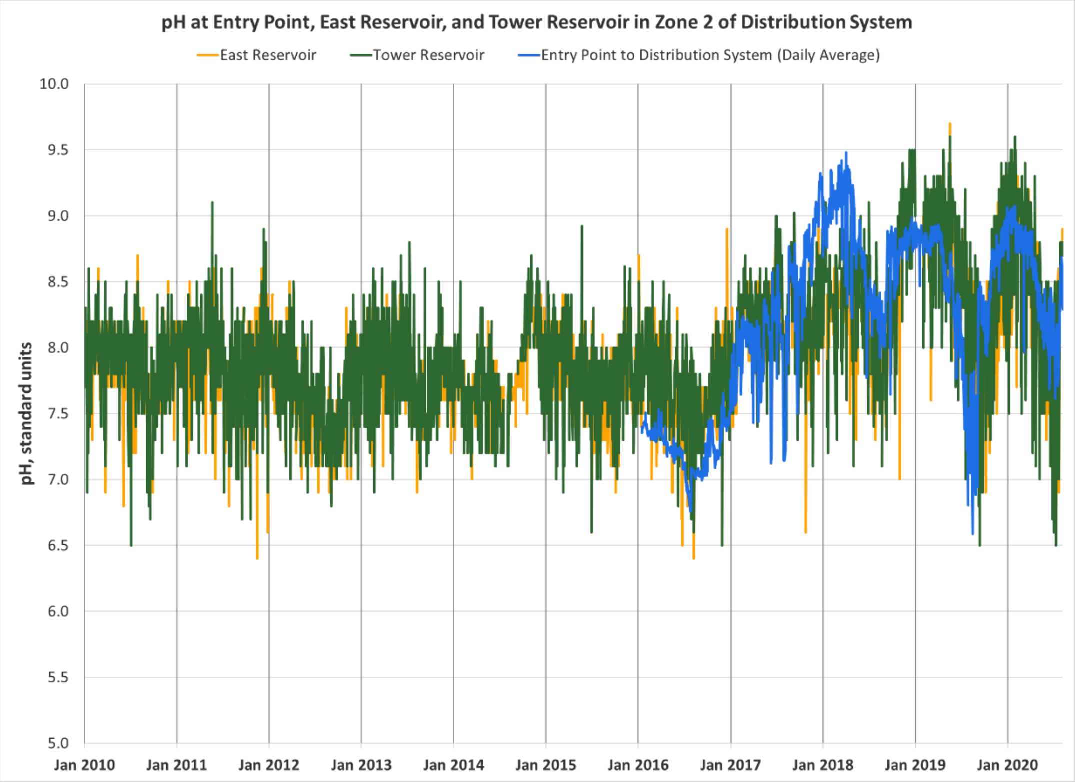

Figure 6: pH at Entry Point and Zone 2 (East Reservoir and Tower Reservoir)

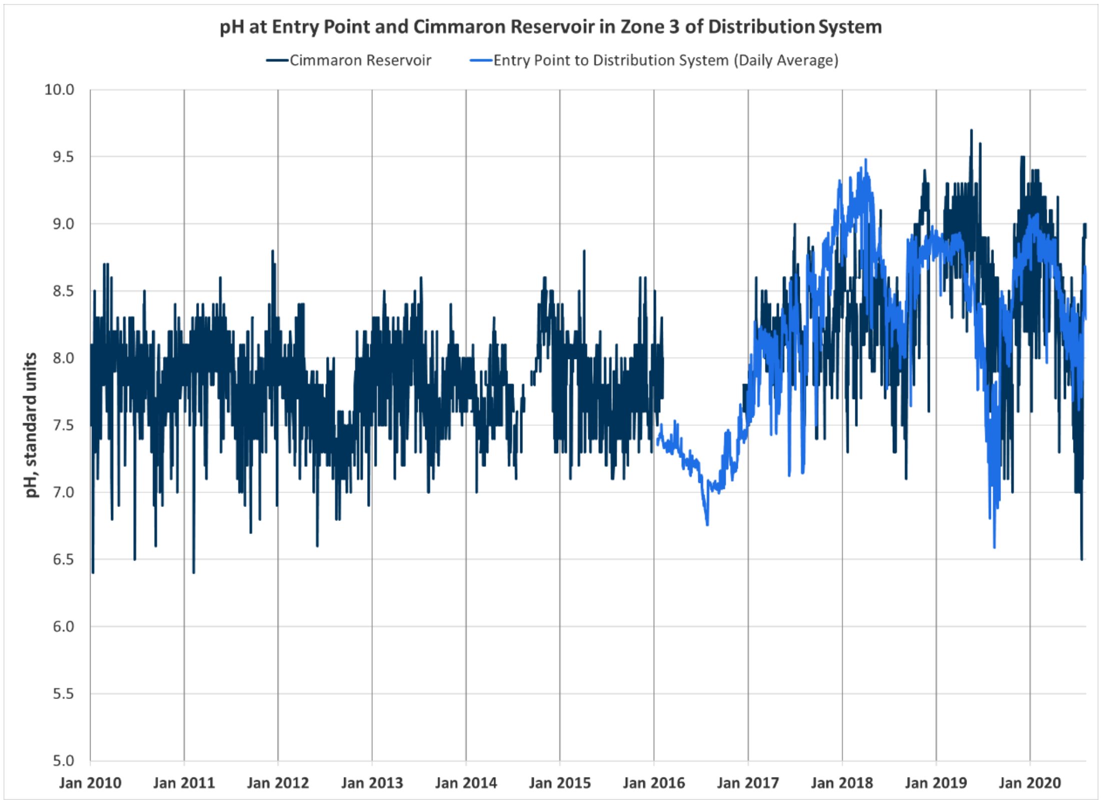

Figure 7: pH at Entry Point and Zone 3 (Cimmaron Reservoir)

Based on findings of Dr. Edwards research at Virginia Tech, pH levels of 9.0 and greater (such as the ones measured in Zones 1, 2 and 3 in 2018, much of 2019, and the start of 2020) combined with the low alkalinity pure water and the use of free chlorine as a disinfectant could have created pitting conditions within copper piping based on research with similar water qualities [1, 2]. Since the City uses a relatively low free chlorine residual of approximately 1 mg/L, it could explain why the onset of pinhole leaks occurred approximately two years after increases in pH from the WTP treating the quality of raw water existing at the time in order to meet the LSI targets.

Chlorine residuals were tracked throughout the distribution system as shown in Figure 8, where Tower Reservoir is near the entry point to the distribution system while Nimbus Reservoir and Zone 6 Reservoir are at the edges of the distribution system and have experienced longer water ages and thus slight degradation in chlorine residuals.

Zones 1, 2, and 3 are located closer to the WTP and therefore have slightly higher chlorine residuals than areas further from the WTP, which could be the reason that most of the pin hole leaks have been detected in the areas closer to the WTP. Chlorine is a strong oxidant that is important for corrosion, so it is reasonable that areas with higher chlorine residuals would experience pin hole leaks faster than other parts of the distribution system. As a comparison, chlorine levels near the WTP could average 1.2 mg/L whereas chlorine levels further from the WTP could average 0.8 mg/L. While 1.2 mg/L is a higher value than 0.8 mg/L, the 1.2 mg/L is not considered a “high” value in drinking water systems where the maximum residual disinfectant level can be up to 4.0 mg/L.

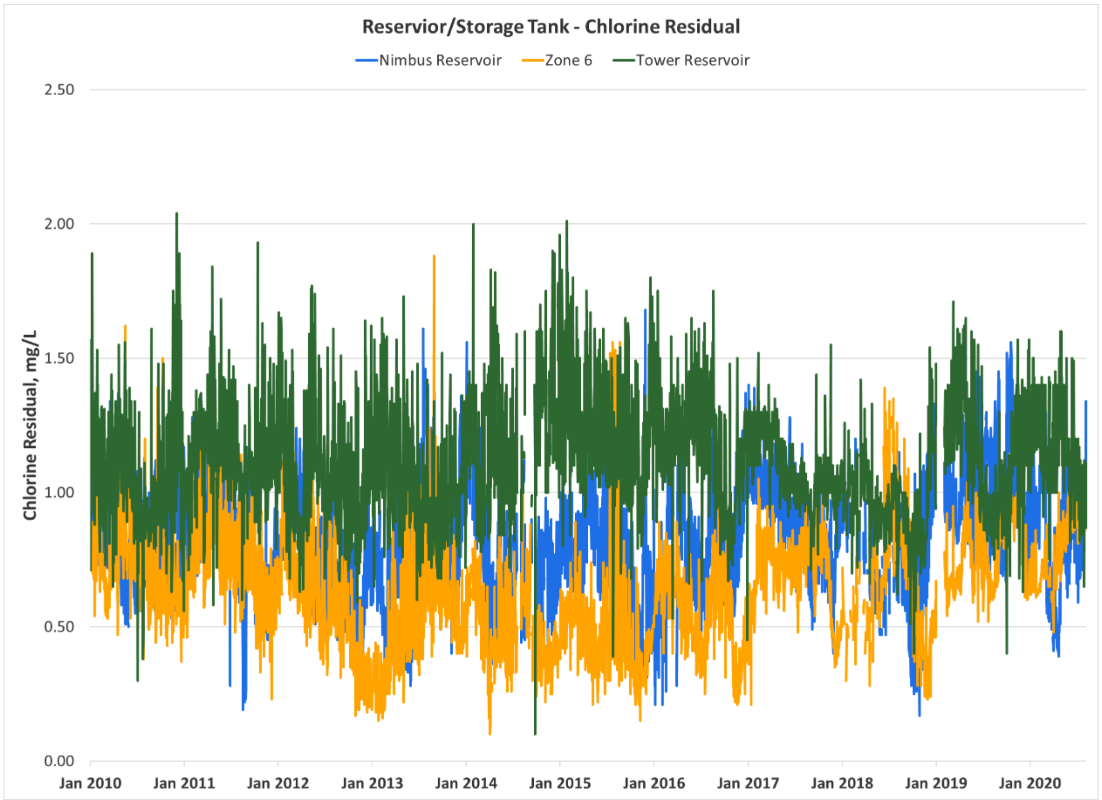

Figure 8: Chlorine Residuals in Select Distribution System Reservoirs

Additional water quality parameters were tracked over time and are included in Appendix A.

A comparison of how water quality can change throughout the distribution system is shown in Figure 9, where pH grab sample data were compared from July 2020 for the entry point, multiple locations in the distribution system at or near locations with pin hole leaks, and at the reservoirs. The samples were collected on different days as the entry point grab sample was collected on July 8, 2020, the distribution system samples were collected on July 24, 2020, and the reservoir samples were collected on July 27, 2020.

To provide extra context to the data, the online pH analyzer from the entry point was included on Figure 9 to show how the pH was measured as 7.9 with the online analyzer on July 8, 2020 yet the grab sample result was 7.4. Additionally, the online analyzer pH result was 8.2 at the entry point on July 24, 2020 when the distribution system samples were collected. Figure 9 shows the variability in pH through the distribution system, as on a single day, the pH levels differ by up to 0.9 pH units when comparing different reservoirs. The distribution system samples show a difference of up to 1.1 pH units. Due to the low buffering capacity of the water it is difficult to maintain a consistent pH, but the swings in pH should be minimized.

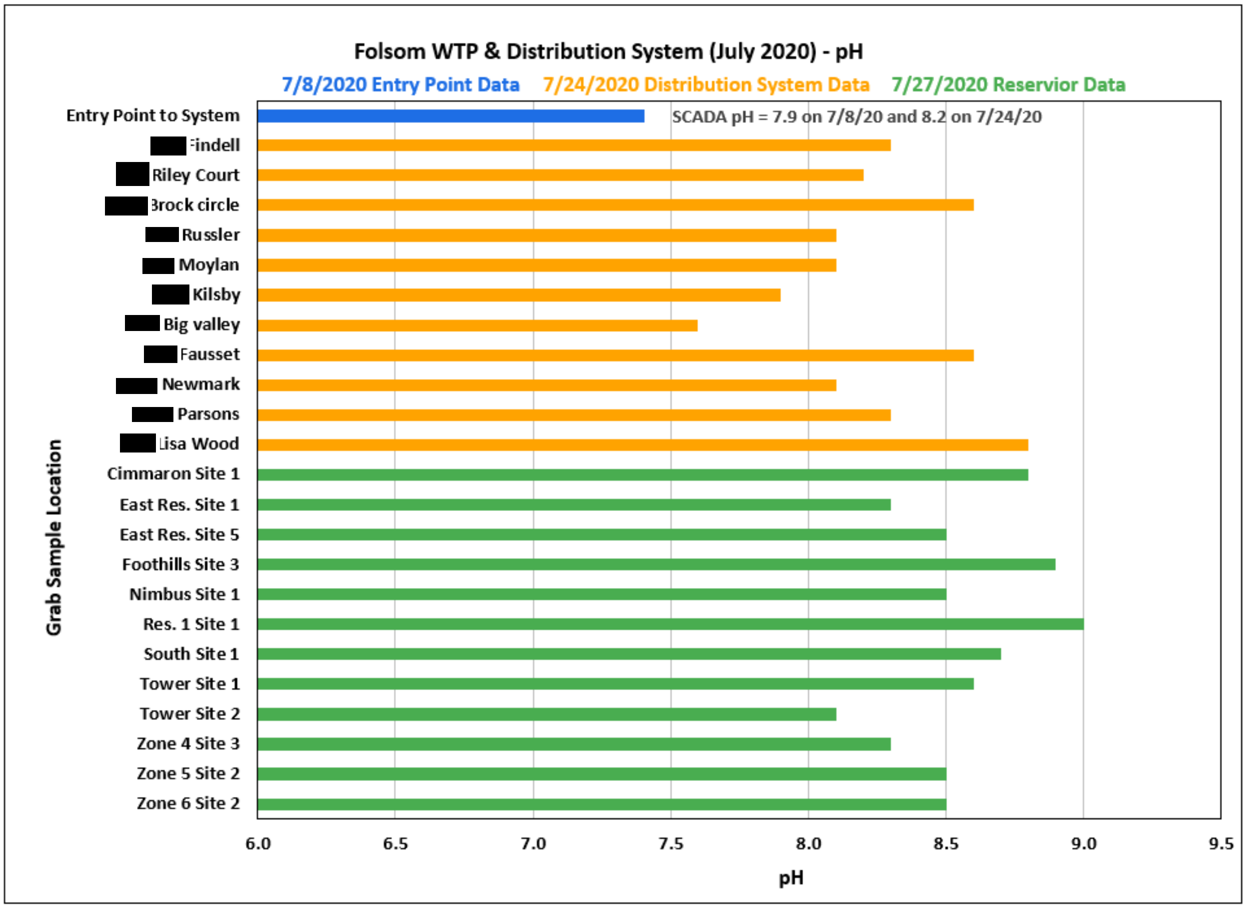

Figure 9: pH from WTP, Reservoirs and Distribution System Grab Samples in July 2020

Chlorine residual data were also plotted in this manner to display how water quality changes throughout the distribution system as shown in Figure 10. It is clear that water quality in the Tower Reservoir is very similar to the entry point data, and then the chlorine residual continues to decrease slowly as it passed through more of the distribution system.

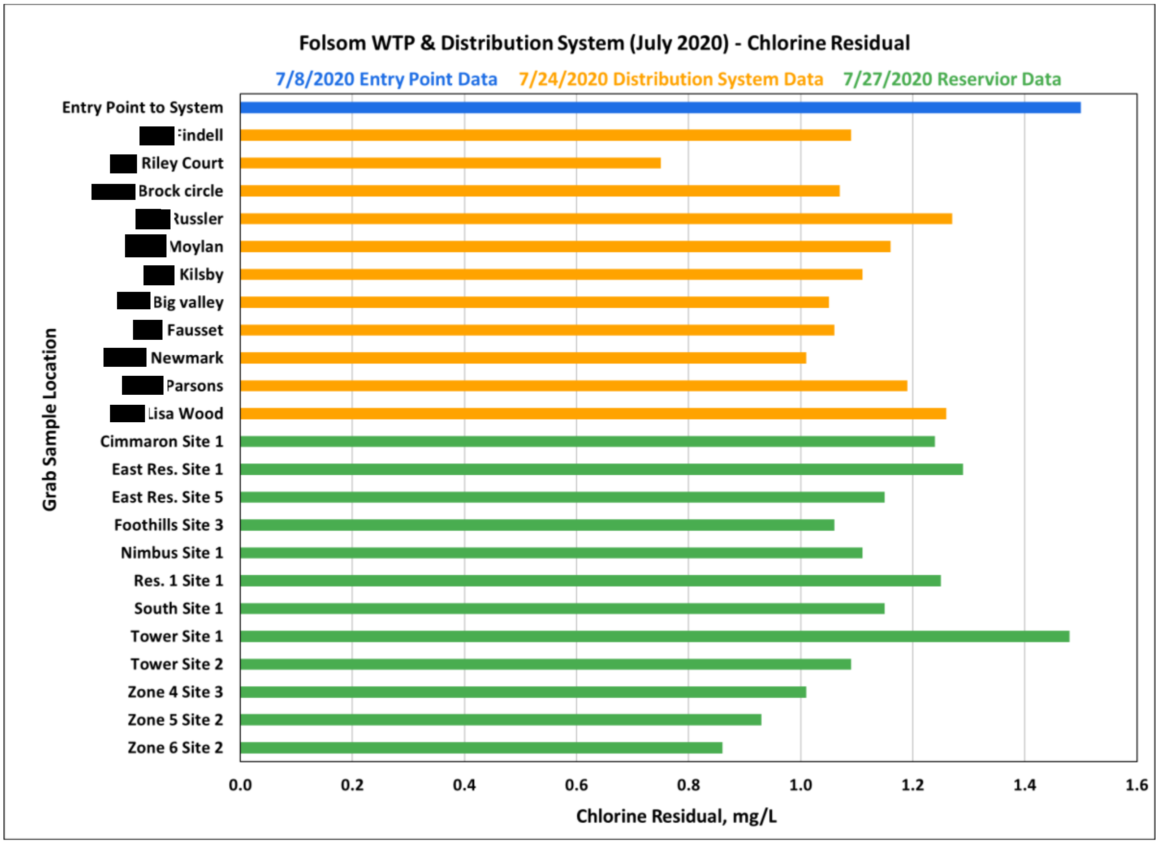

Figure 10: Chlorine Residual from WTP, Reservoirs & Distribution System Grab Samples in July 2020

Additional water quality parameters and a calculated corrosion indicator are shown in this same manner to display changes in water quality throughout the City's system in Appendix A.

5.0 Pipe Scale Analysis

Pipe scale describes minerals or compounds that precipitate out of water and deposit on the interior of pipes. Calcium carbonate is the most common component of pipe scale, but any constituents that attach to the interior of pipes make up the pipe scale. Valuable information can be gained from performing scale analysis, as it allows for the determination of the structure and composition of scales that line the inner surfaces of pipe samples. Scale analysis typically involves multiple different techniques to gather the necessary quantitative and qualitative information that can explain the nature of the scale and in this case the pitting corrosion. The pipe scale analysis techniques consisted of the following:

- Environmental scanning electron microscopy (ESEM) equipped with energy dispersive X-ray spectroscopy (EDS), where the ESEM provided images of the scale from the pipe and EDS provided the associated elemental composition at different locations in the scale.
- Inductively coupled plasma-mass spectrometry (ICP-MS) involved scrapping a sample of the scale from the pipe and dissolving the scale with acid prior to analysis to determine the percent composition of the scale.
- Wall thickness analysis of the pipes was completed using Mitutoyo calipers.
- Sulfide "spot test" analysis was included to determine if sulfide reducing bacteria could be a cause of the pitting.
- Visual inspection of interior and exterior pipe surfaces to identify types of corrosion.

Scale analysis was performed on eight harvested copper pipes from locations that experienced pin hole leaks in the City's distribution system. After the materials were harvested from premise plumbing the samples were shipped to the Virginia Tech ICPMS Metals Analysis Lab for scale analysis. Images of pitting and pinhole leaks in some of the copper pipes are shown in Figure 11.

Pitting corrosion is focused on a small area on the inside of pipes whereas typical surface corrosion that the LCR is written to address involves the entire interior surface of the pipe. LCR monitoring is used to detect if customers are consuming levels of metals (i.e., lead and copper) that could be a health risk. Surface corrosion means that the water is aggressive and can leach metals from the pipe surface and those metals can be found in the water at the tap. Based on the City's LCR compliance record this type of corrosion is not occurring at levels that violate the LCR, which is why the City qualified for triennial monitoring with DDW.

Pitting corrosion is a localized type of corrosion at specific sites the size of the tip of a pen on the interior of pipe walls. Pitting involves the removal of copper ions from a specific site and then they are deposited in corrosion scale around the pit as shown by the blue/green sites in Figure 11. As the pit continues deeper and deeper into the pipe wall, the corrosion scale grows, and the water quality is changed at this microscopic location. The removal of copper ions makes the pit become acidic (more corrosive) and it draws in chloride and sulfate ions to try and regain electroneutrality, but in the process it makes the pit salty (increases corrosivity). These changes in water quality along with changes in flow patterns in the pipe as a result of the buildup of pipe scale create conditions that can continue pitting to the point when a pin hole leak occurs.

Figure 11: Images of Corrosion Pitting in Harvested Copper Pipes

The complete scale analysis report with methodology, data, images, and analysis is presented in Appendix C, and the highlights are included here:

- The primary elemental composition of the corrosion pits was approximately 60 percent copper and 30 percent oxygen, by weight, indicating that the pits were likely copper oxide.
- Copper was the main element found in the pitting corrosion along with trace amounts of aluminum and silicon. Aluminum is notable as recent research has shown aluminum concentrations of 0.5 percent by weight or more can catalyze copper pitting in very clean waters at pH greater than 9 with free chlorine [1, 4], which describes the City's treated water at various times throughout the year. The sources of aluminum were not identified in this analysis and it is recommended that the City continue to conduct lab analysis for Aluminum. Aluminum is recognized by the EPA under its National Secondary Drinking Water Regulation with an MCL of 0.2 mg/L. The City's records indicate that the treated water samples indicate a "non-detect" for Aluminum. Pitting can potentially occur due to a pH above 9, low alkalinity, and free chlorine, but the presence of aluminum could speed up the reactions since the aluminum present in the pipe scale was greater than 0.5 percent in all samples.
- The sulfide "spot test" came back negative, thus, eliminating sulfite reducing bacteria as a potential cause for the pitting.
- There was no evidence of microbial activity in the harvested pipes; therefore, microbial induced corrosion was ruled out as a cause for the pitting.

- The copper pipe thickness ranged between 81 and 91 percent of the American Society for Testing and Materials (ASTM) specification for Type M copper, but since the harvested pipes were installed 20-50 years ago, they were deemed not defectively thin.
- Some leaks appeared to have sealed themselves through a process known as autogenous repair.
- There was no observed difference in the pipe scale when comparing the pipes on cold water services with the pipes on hot water services. This area of research is not well defined yet.
- The results of scale analysis indicate that pH increases (over the last few years), low alkalinity (<40 mg/L as $CaCO_3$) pure water treated with free chlorine could potentially contribute to pitting.

6.0 Conclusions

The City has produced a high-quality potable water that under most circumstances provided the optimal corrosion control treatment as demonstrated by historical compliance with the LCR. However, the purity of this water source resulted in a rare set of conditions that can contribute to pitting conditions in copper pipe. The source water that the City treats contains low levels of alkalinity (<40 mg/L as $CaCO_3$), calcium, total organic carbon, TDS, turbidity, etc.. Waters low in calcium and alkalinity (<40 mg/L as $CaCO_3$) along with a pH above 9 and the use of free chlorine for disinfection could contribute to pitting in copper pipe, especially at sites with impurities in the pipe material or at sites where particulate settled.

Research studies have been able to replicate pitting corrosion on copper pipes in laboratory settings when the conditions used a pH above 9, low alkalinity waters (<40 mg/L as $CaCO_3$) treated with free chlorine [1, 2]. These studies have shown that pitting corrosion can occur on electrolytic copper (i.e., a perfect copper surface with no impurities), which means that while settled particulate or impurities can provide a site to start pitting, their presence is not required in all situations. This analysis did not include replicating the City's water quality conditions, but rather, draws conclusions from previous studies with similar water quality parameters to the City.

These research studies included results and conclusions drawn from full-scale systems that experienced pitting and pin hole leaks in copper pipes, and often the addition of orthophosphate was able to hinder pit initiation and slow or mitigate pit propagation.

Once a corrosion pit is initiated it creates an area where copper ions are removed from the pipe surface, which creates a localized acidic area and the ionic strength increases as constituents like chloride and sulfate are drawn to the area to maintain electroneutrality [2]. The created localized conditions of an acidic and salty environment can lead to pit propagation and can result in pin hole leaks.

Literature indicates that other alternatives (increasing alkalinity, adding silicates, decreasing the chlorine residual, or decreasing the pH) to reduce copper pitting have been examined but none of these have been as effective as adding orthophosphate [2]. Due to the urgency on the City's part to diagnose the cause of copper pin hole leaks and, if available, implement a water quality solution quickly, it appears that orthophosphate is the most rational solution.

The use of orthophosphate has been shown to inhibit pitting in aggressive waters by hindering pit initiation as a passivating scale will develop on the interior of copper pipes, and it can help to slow or even mitigate pit propagation on pits that are already initiated. It is critical to use an appropriate dosage of orthophosphate, which is why monitoring in the distribution system is necessary as research has not defined a critical threshold level of orthophosphate as it depends on the water quality and system specific conditions (e.g., flow velocity and frequency) [2].

Orthophosphate is a commonly used corrosion inhibitor that is recommended by US EPA for use in drinking water applications. Orthophosphate is a safe additive to drinking water, and the proposed chemical is approved by DDW and is certified by the National Sanitation Foundation International (NSF) to meet purity standards to be NSF 60 approved. The aesthetics of the City's water should remain the same with the addition of orthophosphate, but the pitting should decrease or stop.

7.0 Recommendations

Due to the immediacy of the copper pin hole leaks occurring throughout the City's system, it was important that the City was continually updated throughout this short study and that the City was informed of preliminary conclusions and early recommendations to minimize the time to begin implementing potential solutions. Early analysis identified a potential contributing factor, along with pipe impurities or settled particulate, for the pin hole leaks could be a result of high pH (>9.0), low alkalinity (<40 mg/L as $CaCO_3$) water with a free chlorine residual and discussions with the City described that research has shown the use of orthophosphate to be effective at mitigating the pitting in copper pipe. After these early discussions on September 18, 2020, it was recommended that the City reach out to DDW to discuss the situation and determine the steps necessary if the City wanted to begin dosing orthophosphate.

The City discussed the pin hole leaks and initial water quality findings with DDW on September 18, 2020 and was provided a letter on September 30, 2020 that granted the City permission to begin feeding orthophosphate in attempt to mitigate copper pitting based on a neighboring utility's experience treating the same source water using a phosphate-based corrosion inhibitor. Once the City was granted permission to start feeding orthophosphate, the City consulted Black & Veatch on where to place the chemical feed, what type of dosages should be targeted, as well as monitoring that should be completed. The following recommendations were provided in response to the DDW authorization to feed orthophosphate:

1. Target a finished water pH of 8.5 using the current lime dosing system to adjust pH. Confirm pH by measuring pH at the effluent of Reservoir 1 & 2, which is the entry point to the distribution system.
2. An orthophosphate chemical was recommended over a polyphosphate or blended phosphate chemical due to the success of orthophosphate in both laboratory studies and full-scale practices [2, 1].
3. In order to expedite the use of orthophosphate, the City could use an existing feed point at the influent to the chlorine contact tank that is not being used.
4. Dosing pumps should be purchased based on the flow range and dosage range expected and ensure compatibility with chemical safety. Chemical storage and maintenance practices should account for any safety considerations with orthophosphate.
5. The recommended dosages and monitoring for orthophosphate were as follows:
    a. The dosages of orthophosphate are expressed below as mg/L as phosphorous (P), and it is critical to make this distinction as sometimes phosphate-based chemical dosages/residuals can be expressed as phosphate (PO_4). These two expressions would result in two different concentrations. A concentration of 1 mg/L as P would need to be multiplied by 3.06 to express the concentration as 3.06 mg/L as PO_4 due to the difference in molecular weight of P and PO_4. It is also critical to account for the concentration of the orthophosphate chemical supplied as it will need to be accounted for in dosing rates. It is recommended that orthophosphate concentrations are always written with "as P" to limit confusion.
    b. During the first week use an orthophosphate dosage of 0.1 mg/L as P and confirm the dosage through measurements of orthophosphate residual at the effluent of the

chlorine contact tank to adjust dosing if necessary. Measure orthophosphate at Reservoir 1 & 2 in the finished water after lime addition.

   c. Measure orthophosphate residual at kitchen taps in at least 5 houses in the distribution system to determine if orthophosphate is still present in the bulk water or if it has reacted with distribution system materials and building plumbing to form a passivating scale thus the residual would be less that what was measured at the entry point to the distribution system. Employee residences were noted as ideal sampling locations throughout the distribution system due to the frequency of sampling.

   d. After the first week of feeding orthophosphate, increase the dosage to 0.2 mg/L as P and confirm the dosage through measurements of orthophosphate residual at the effluent of the chlorine contact tank to adjust dosing if necessary. Measure orthophosphate at Reservoir 1 & 2 in the finished water after lime addition.

   e. After the second week of feeding orthophosphate, increase the dosage to 0.3 mg/L as P and confirm the dosage through measurements of orthophosphate residual at the effluent of the chlorine contact tank to adjust dosing if necessary. Measure orthophosphate at Reservoir 1 & 2 in the finished water after lime addition.

   f. Continue to dose 0.3 mg/L of orthophosphate (as P) and measure residual at kitchen taps of homes throughout the distribution system to determine at what point the orthophosphate residual matches what was fed at the WTP; thus, indicating that the premise plumbing and bulk water are at equilibrium with respect to orthophosphate.

   g. Continue to monitor for pin hole leaks and track if customer reporting of leaks decreases as a result of feeding orthophosphate.

   h. Monitor for any additional water quality parameters outlined in the temporary authorization from DDW at the locations and frequencies specified.

6. Due to the quick startup of the orthophosphate chemical feed system, grab samples should be collected until the point when online analyzers can be installed and linked to SCADA systems to monitor dosing and residuals. Once online analyzers are in service, it is recommended that grab samples be collected to verify calibration of online analyzers.

7. Once orthophosphate dosing begins, it is not recommended that the City stop feeding orthophosphate as pitting could worsen if the equilibrium conditions between the pipe surface and the bulk water were not maintained. This conflicts with DDW's temporary authorization to feed orthophosphate through November 30, 2020. This item should be discussed with DDW.

8. Follow all instructions in the DDW temporary authorization for emergency operation of orthophosphate treatment process.

Additional recommendations not related to the orthophosphate feed include the following:

9. Continue to monitor for aluminum in the finished water to comply with the EPA's secondary MCL of 0.2 mg/L at select reservoirs, and at locations in the distribution system like resident taps to determine the source of aluminum on the interior of copper pipes that could be a contributing factor for the pin hole leaks. Historic water quality sampling reports show the City's compliance with this secondary MCL.

10. Monitor for pH at the effluent of Reservoir 1 & 2 and compare with the online analyzer pH readings at the High Service Pump Station to determine if the lime reaction was still occurring at the point of analysis (HSPS sample location) resulting in the daily pH fluctuations.

8.0 References

[1] K. D. R. P. S. R. L.-S. M. E. a. C. N. Emily Sarver, "Copper pitting in chlorinated, high-pH potable water," *Journal AWWA,* vol. 103, no. 3, pp. 86-98, 2011.

[2] E. S. a. M. Edwards, "Inhibition of Copper Pitting Corrosion in Aggressive Potable Waters," *International Journal of Corrosion,* vol. 2012, p. 16, 2012.

[3] U.S. Environmental Protection Agency, "Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems, EPA 816-B-16-003," U.S. Environmental Protection Agency Office of Water (4606M), Washington DC, March 2016.

[4] J. a. E. M. Rushing, "Effect of Aluminum Solids and Chlorine on COld Water Pitting of Copper," *Corrosion Science,* vol. 46, pp. 3069-3088, 2004.

Appendix A. Additional Water Quality Results

Figure 12 shows chlorine residuals measured at reservoirs and storage tanks throughout the City's distribution system using online analyzers from 2010 to 2020. Figure 13 shows the seasonal temperature changes throughout the system, and just the data from Tower Reservoir are displayed to improve the interpretation of the data from 2010 to 2020.

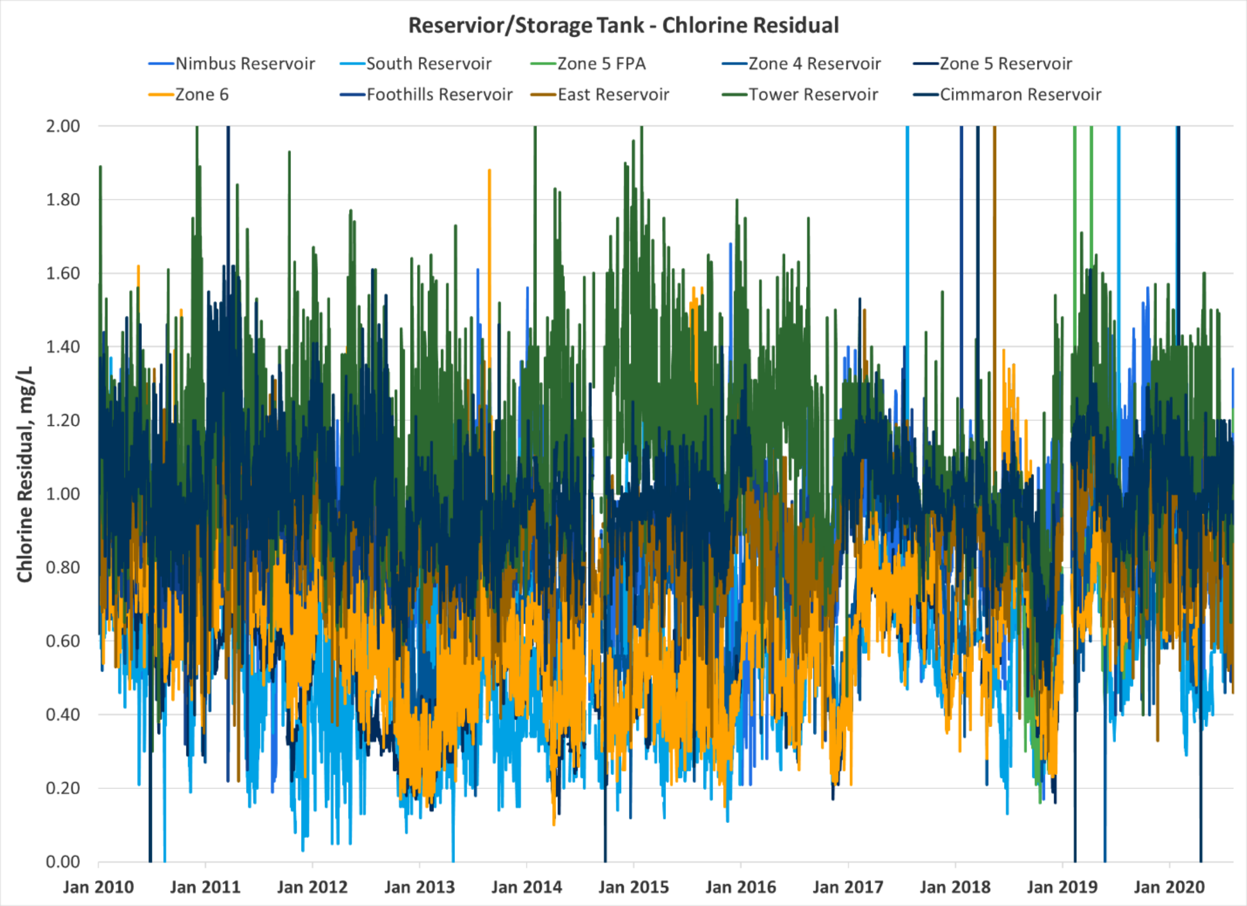

Figure 12: Chlorine Residuals at Reservoirs and Storage Tanks Throughout the Distribution System

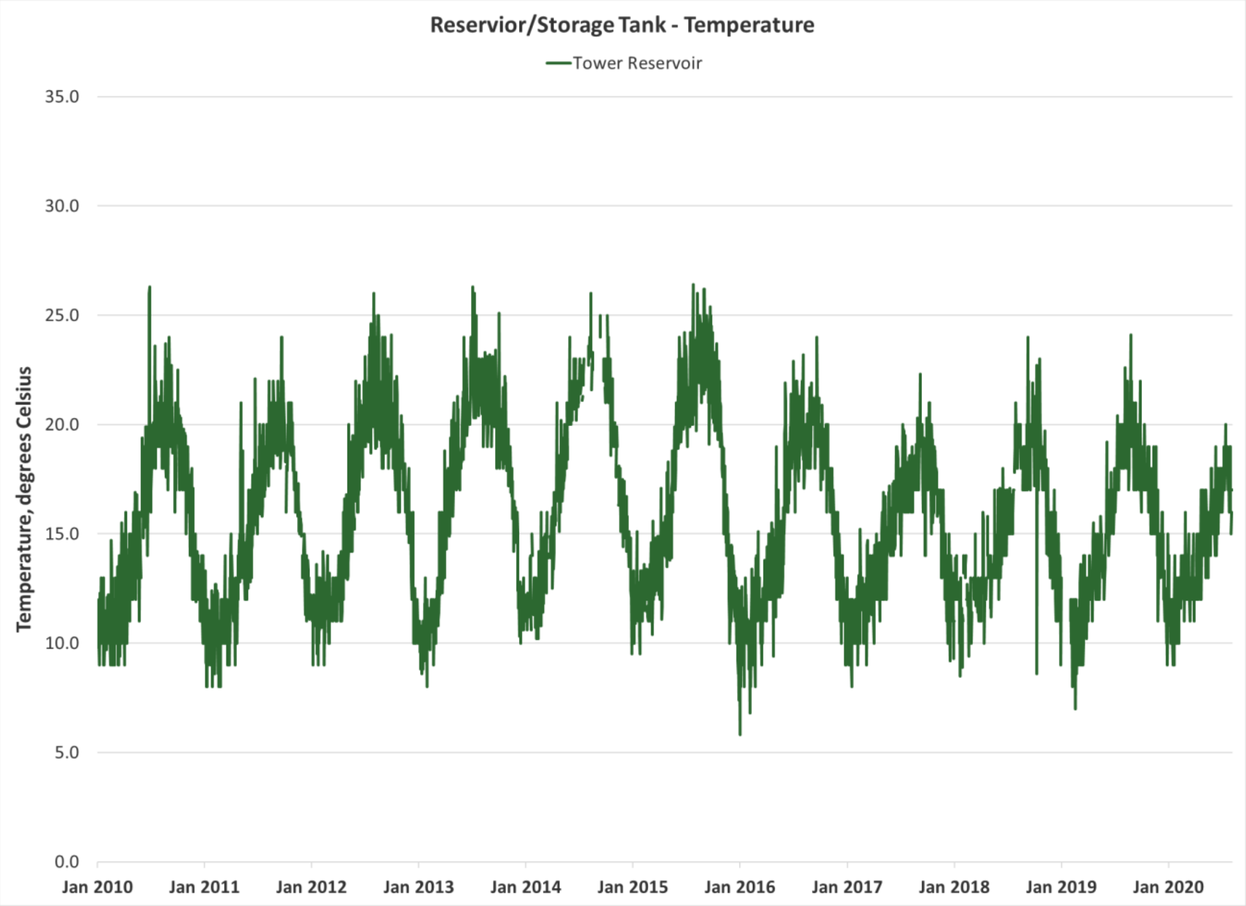

Figure 13: Temperature Data Collected at the Tower Reservoir

Figure 14 through Figure 22 depict water quality parameters measured in grab samples at the entry point to the distribution system from 2010 through 2020 as well as a calculated corrosion indicator of LSI. These data were from discrete samples collected on individual dates and do not represent averages.

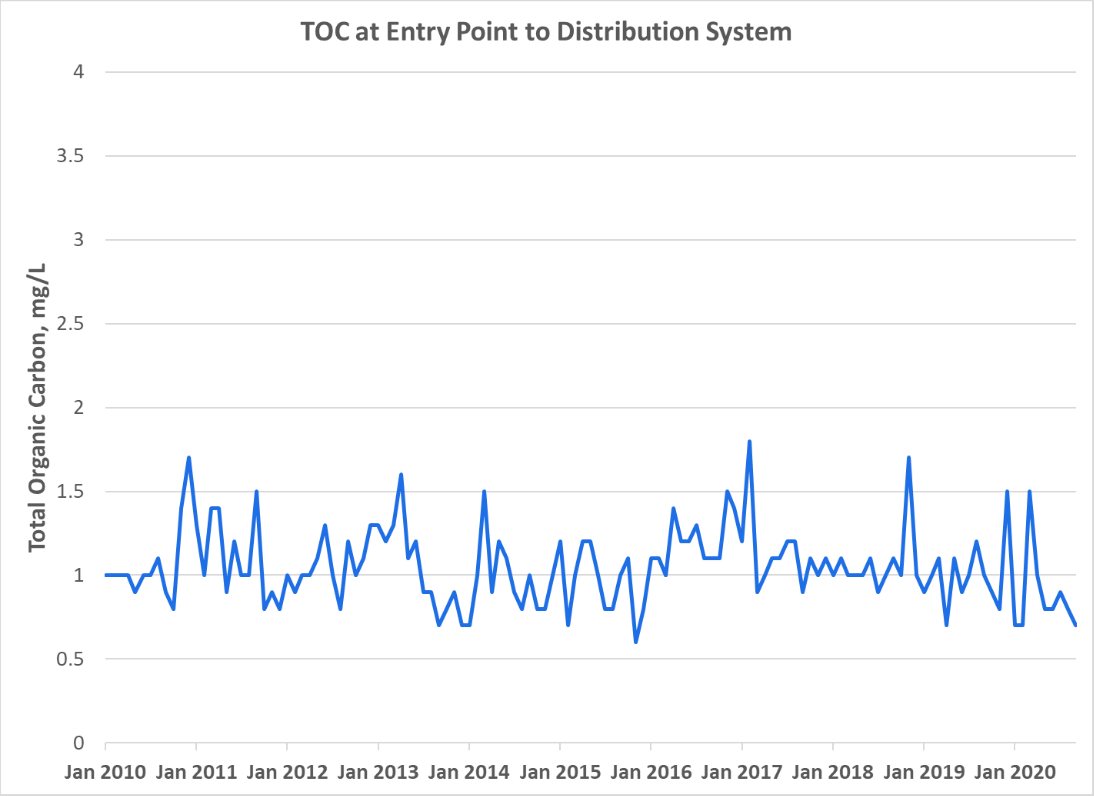

Figure 14: TOC from Grab Samples Collected at the Entry Point to Distribution System

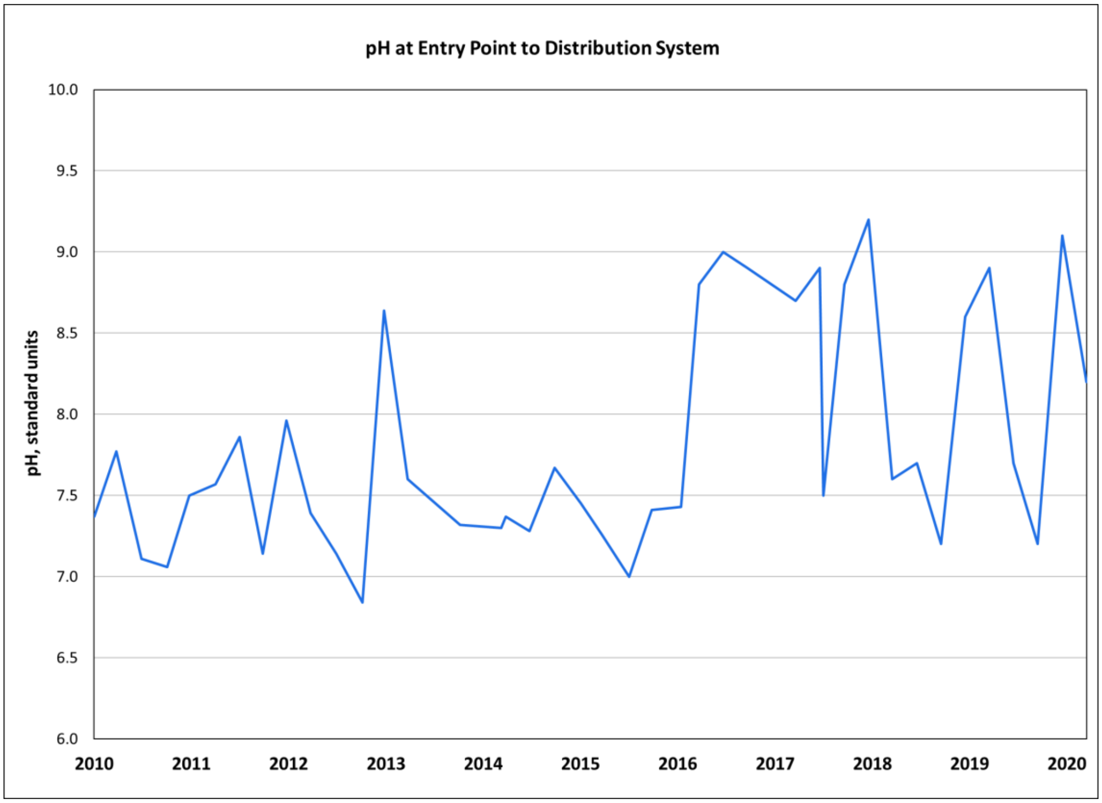

Figure 15: pH from Grab Samples Collected at the Entry Point to Distribution System

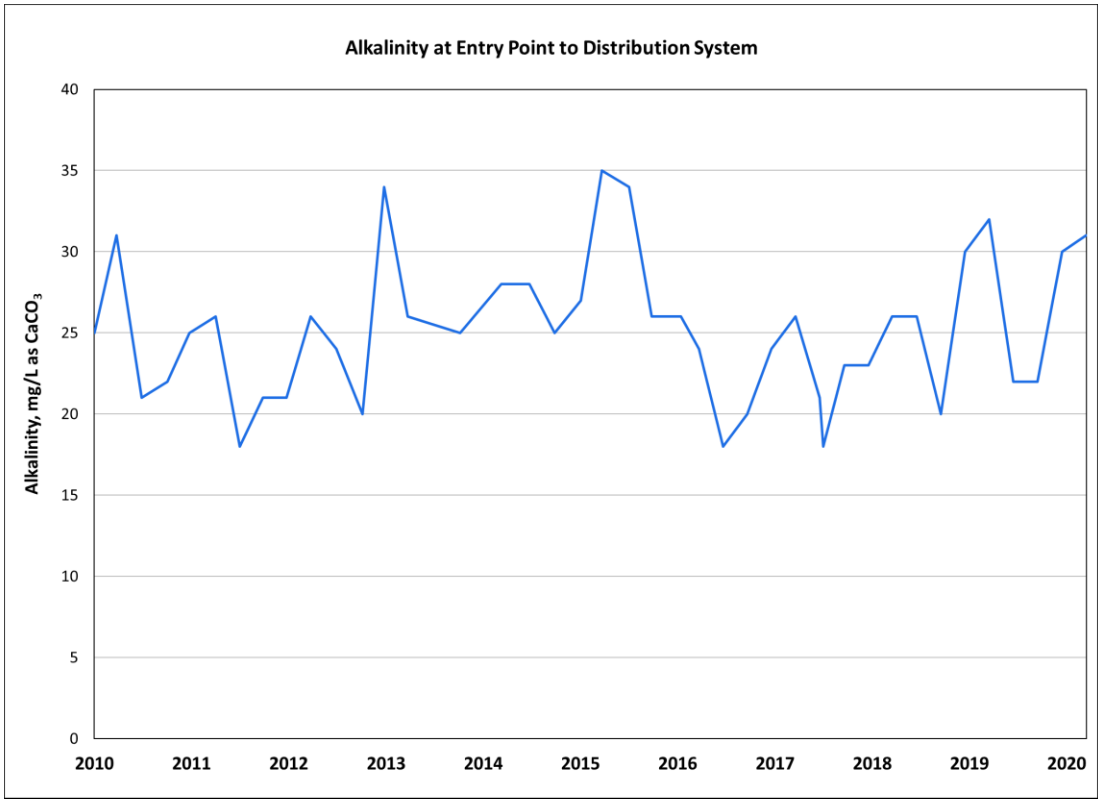

Figure 16: Alkalinity from Grab Samples Collected at the Entry Point to Distribution System

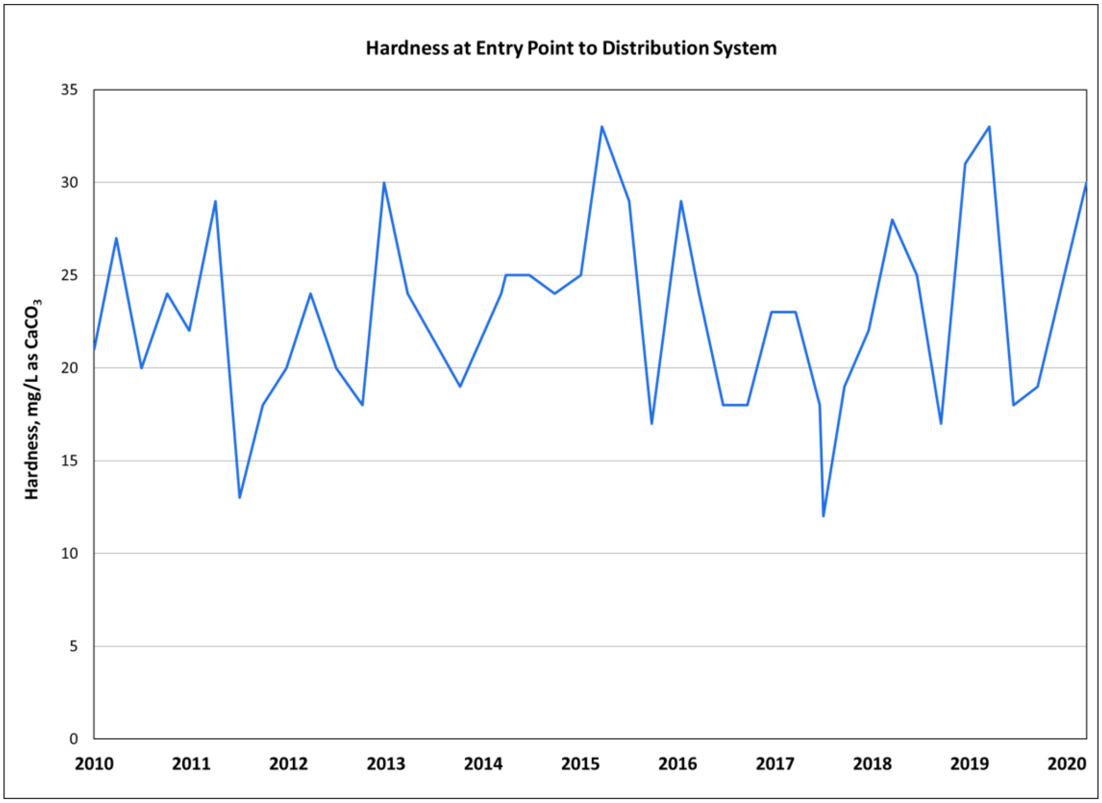

Figure 17: Hardness from Grab Samples Collected at the Entry Point to Distribution System

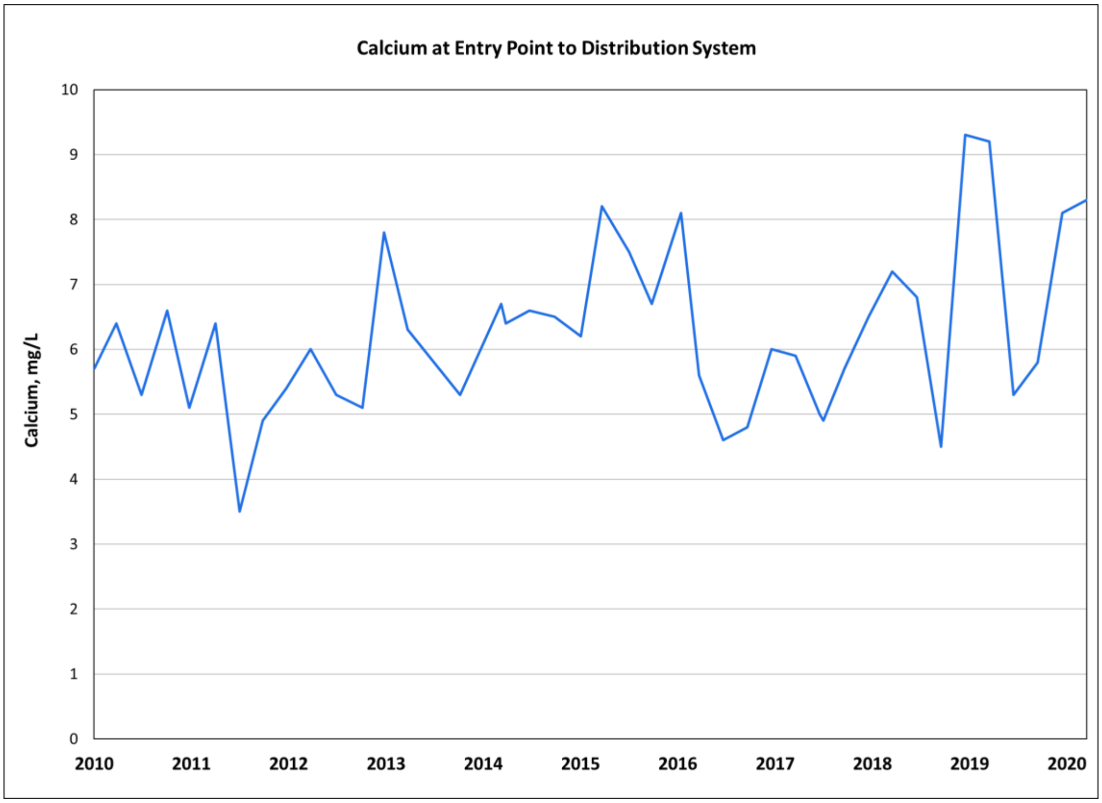

Figure 18: Calcium from Grab Samples Collected at the Entry Point to Distribution System

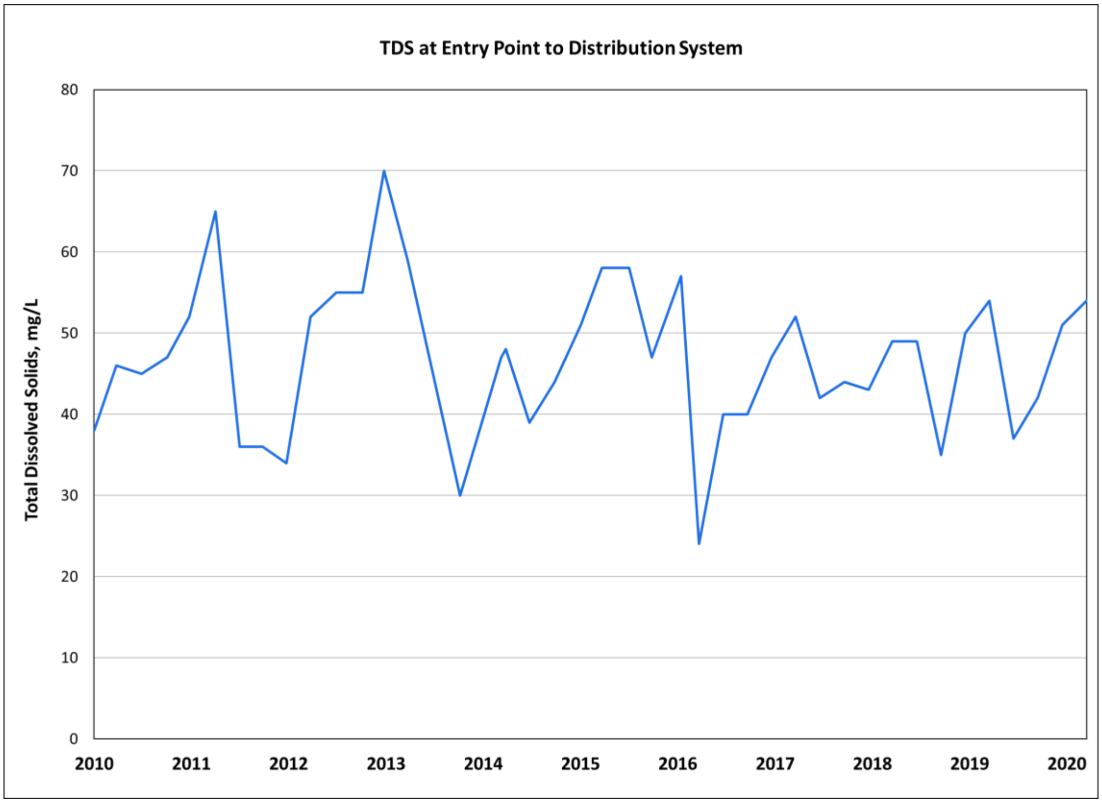

Figure 19: TDS from Grab Samples Collected at the Entry Point to Distribution System

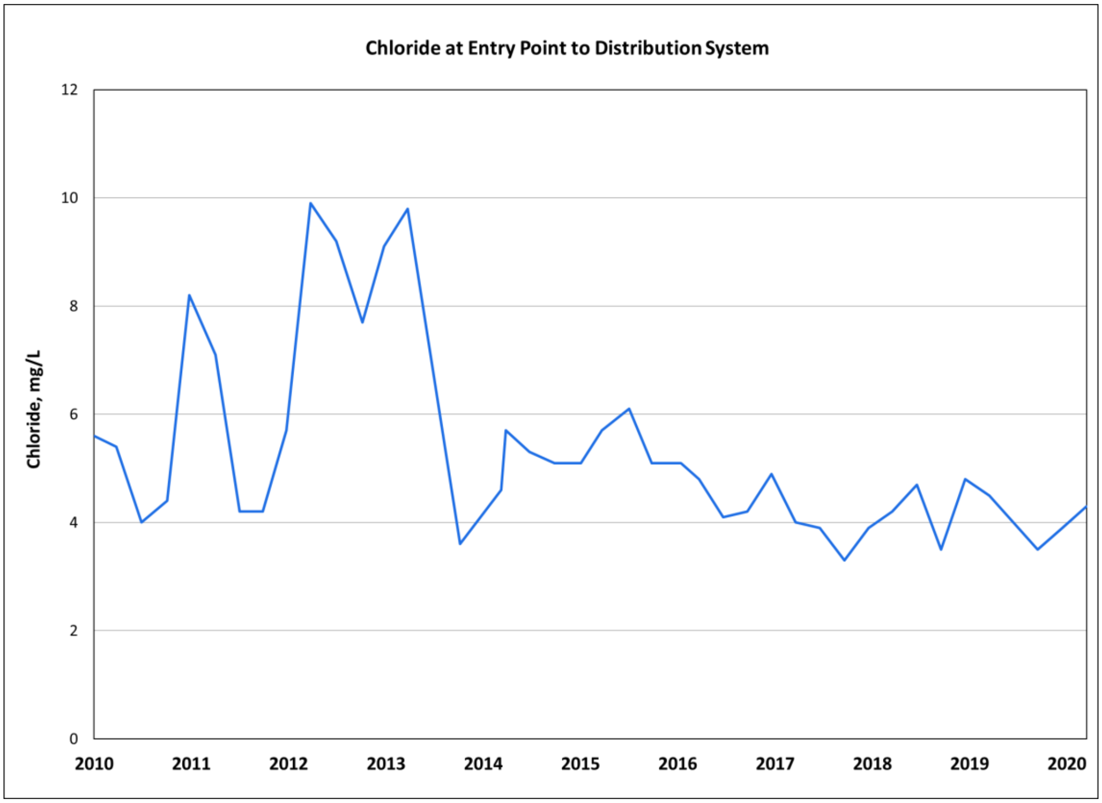

Figure 20: Chloride from Grab Samples Collected at the Entry Point to Distribution System

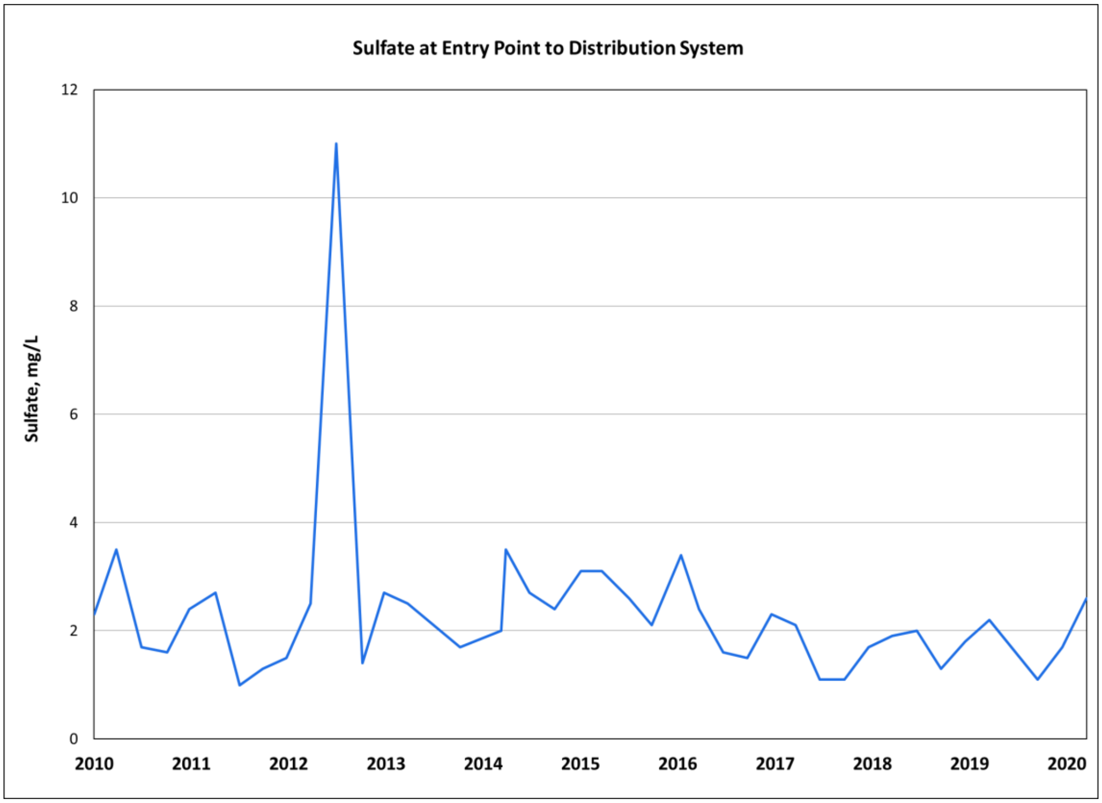

Figure 21: Sulfate from Grab Samples Collected at the Entry Point to Distribution System

The City's operating permit for corrosion control treatment uses lime addition to adjust pH as a way to achieve a desired LSI target. In order to increase the LSI, the City increases the concentration of lime to increase the finished water pH, which also results in increases in alkalinity and calcium that further increase LSI. The City has operated the WTP to meet its permit for finished water quality, and the City raised the pH to keep LSI from being more negative.

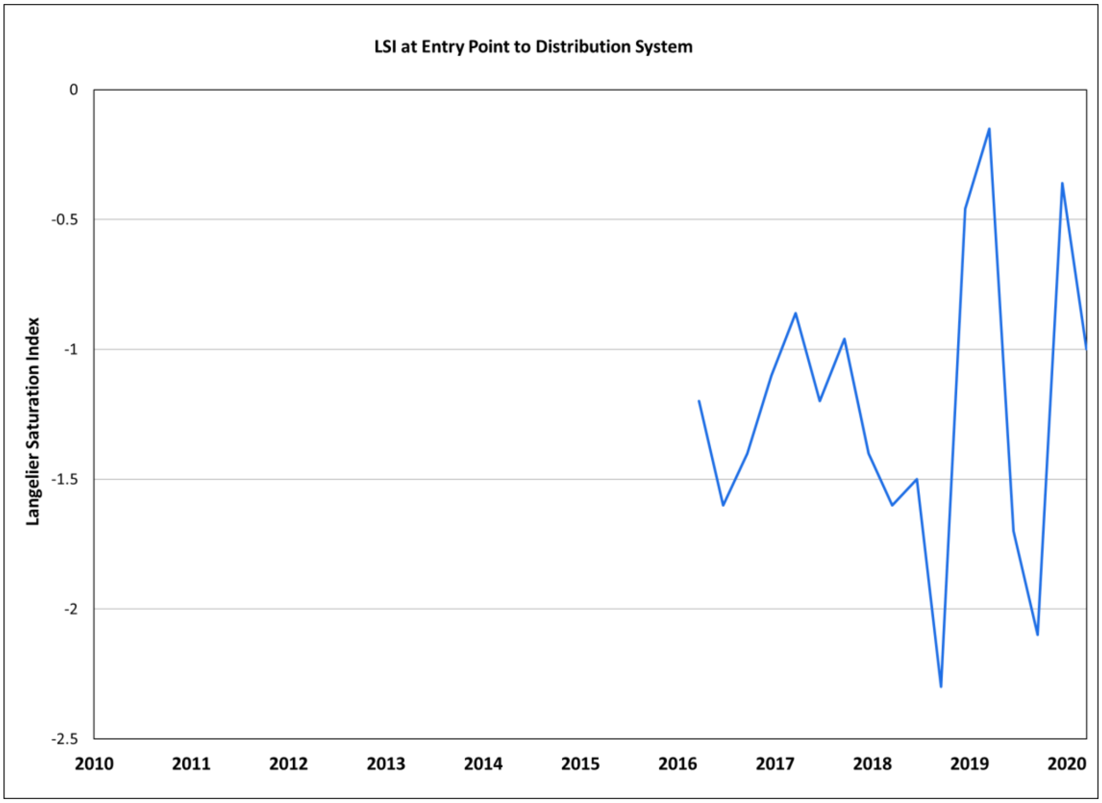

Figure 22: LSI Calculated from Grab Samples Collected at the Entry Point to Distribution System

Figure 23 through **Error! Reference source not found.** show the changes in alkalinity and the calculated corrosion indicator, LSI, as the water travels throughout the distribution system for July 2020 data.

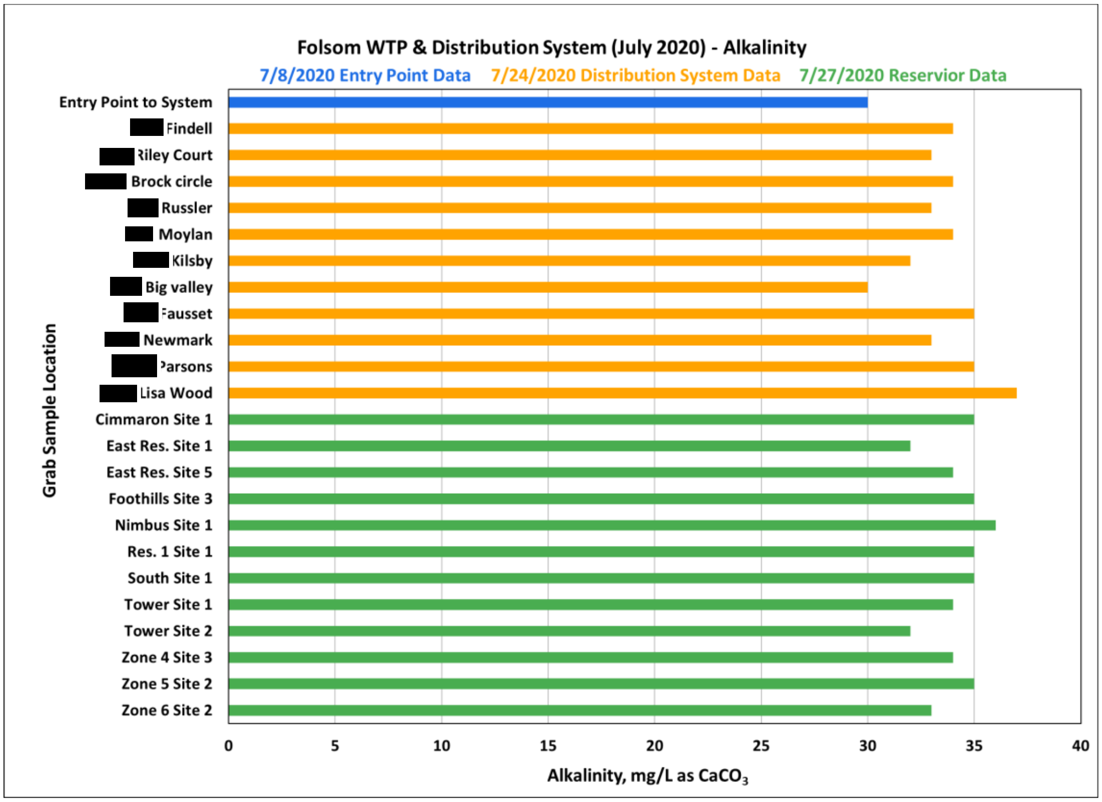

Figure 23: Alkalinity from WTP, Reservoirs and Distribution System Grab Samples in July 2020

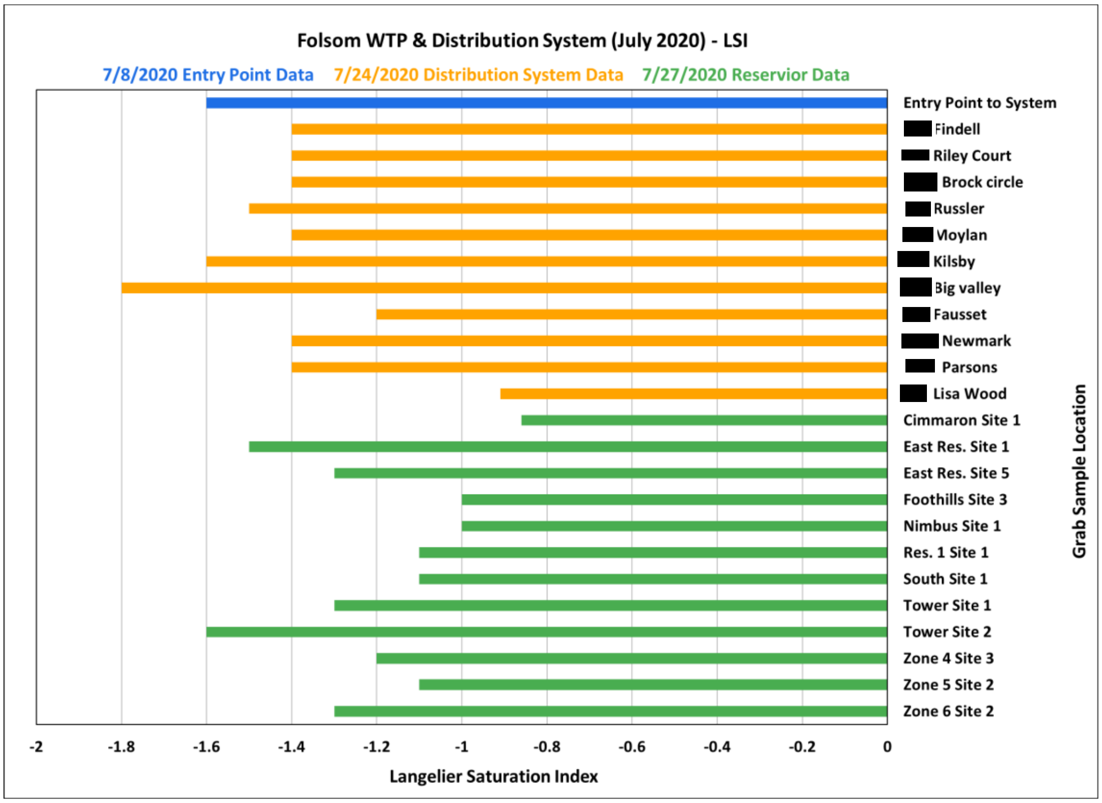

Figure 24: LSI Calculations from WTP, Reservoirs and Distribution System Grab Samples in July 2020

Appendix B. Pipe Harvesting and Transportation Protocol

Copper pipes from the City of Folsom's distribution system should be harvested from locations where pin hole leaks were discovered in the copper pipes. Up to six copper pipe segments will be analyzed in this project. The length of the harvested copper pipe segments should be at least 12 inches to include areas with pin hole leaks and areas without pin hole leaks. If copper pipes are harvested from different locations throughout the distribution system, it could provide a broader understanding of the reasons for the leaks.

While some disturbance of the pipe scale is unavoidable, care should be taken to avoid unnecessarily or excessively disturbing the pipe scale. If possible, when cutting pipe avoid the use of reciprocating saws or saws with an abrasive cutting wheel as these cause excessive pipe vibrations. Ratcheted guillotine blades (i.e., PVC cutter) work well to cut the pipes with less disturbance.

Pipe sections are likely currently filled with water. This water should be removed during pipe extraction. Each pipe section should be labeled so that it can be identified. Labels could be written on the pipe section in permanent ink or a tag could be attached with tape. The label on each pipe segment should include the following:

- Address
- Location within building if more than one pipe is harvested from same address
- Date of pipe installation (if known).

The pipes should be left dry after harvesting. There is no need to cap the pipes after harvesting.

All harvested pipes should be wrapped in bubble wrap, and carefully placed in a box for shipping with no space for the pipes to shift. Analysis of the pipe specimens will be conducted at Virginia Tech in Dr. Marc Edwards' laboratory.

Pipes should be shipped to the following location for analysis:

Attention: Jeffrey Parks
Department of Civil and Environmental Engineering
Virginia Tech
1145 Perry Street
408 Durham Hall
Blacksburg, VA 24060

Appendix C. Scale Analysis Report from Virginia Tech

Evaluation of Copper Pitting in Folsom, California

Prepared for:
Black & Veatch
8400 Ward Parkway
Kansas City, MO 64114

Prepared by:
Dr. Jeffrey Parks
Dr. Marc Edwards
Virginia Polytechnic Institute and State University
1145 Perry St.
418 Durham Hall
Blacksburg, VA 24061

October 16, 2020

INTRODUCTION / BACKGROUND

Folsom, CA currently treats surface water from Folsom Lake to provide potable water to its customers. Treatment is conventional and uses aluminum chlorohydrate (ACH) as coagulant, lime for pH adjustment, and sodium hypochlorite for disinfection. Corrosion control is achieved by the lime addition to maintain pH between 8.0 and 8.7. Alkalinity of the source water is 18 – 35 mg/L as $CaCO_3$, with an average of about 25 mg/L as $CaCO_3$. Hardness averages about 23 mg/L as $CaCO_3$. Other water quality parameters of interest include chloride (average about 5.3 mg/L) and sulfate (average about 2 mg/L).

Recently customers have been experiencing pinhole leaks in their copper plumbing systems. The objective of this study was to examine whether the problems experienced by Folsom customers are similar to established causes of pitting corrosion and provide recommendations based on our prior research and experience.

MATERIALS AND METHODS

Several copper pipes with pinholes from Folsom were harvested and shipped to Virginia Tech for forensic analysis. Locations for each of these pipes is shown in Table 1. The eight pipes were cut longitudinally so that the interior surfaces could be examined. The thickness of each copper pipe was determined using a set of Mitutoyo calipers. There are frequent differences in hot and cold water pitting but no distinction was made between cold and hot water piping in this study; however, the type of pitting observed here is more common in cold water based on prior experience.

Table 1. Locations of copper pipes evaluated

Pipe ID	Year	Description
A	1989	1" Cu pipe 1' long with tee
B	1968	1" Cu pipe 9" long with tee
C	1986	3/4" Cu pipe 26" long
D	1985	1" Cu pipe 17" long
E	1976	3/4" Cu pipe 20" long
F	1999	1" Cu pipe 14" long (Type M)
G	1991	1"Cu pipe 13" long w/ putty
H	1988	1/2" Cu pipe 4" long

Several pits were removed for analysis by inductively coupled plasma mass spectrometry (ICP-MS) and by electron scanning microscopy with an attached X-ray energy dispersive system (SEM-EDS). A portion of the pit was weighed and placed in a 125 mL HDPE bottle with 80 mL of deionized distilled water and 20 mL of trace metal grade nitric acid. Bottles were placed in an oven at 60 °C for one day to allow the solid to dissolve. The resultant solutions were diluted 1:10 and analyzed by ICP-MS for metals concentrations. Another portion of the pit was mounted and analyzed directly by SEM-EDS for elemental composition.

One pit was selected for a ‘spot test’ analysis. Since sulfide attack was one possible established cause for the pinholes, the method described by Feigl and Anger in “Spot Tests in Inorganic Analysis’ was utilized[1]. In this method a small drop of a sodium azide-iodine solution is placed on the pit covering one of the pinholes. Any solid metal sulfide present would immediately react and result in the evolution of nitrogen gas, which can be visually detected by the bubbles on the surface of the pit.

Historical water quality data was also obtained and evaluated to discern possible causes of the pitting.

RESULTS AND DISCUSSION

Representative photographs of the interior surfaces of the eight copper pipes are shown in Appendix 1, **Figures A1.1-A1.8**. Each pipe had pitting on the interior surfaces and some outer surface corrosion due to water escaping through the pinhole leaks. Some leaks appeared to have sealed themselves, via a process known as autogenous repair.

The sulfide ‘spot test’ on several of the pits in Pipe D did not show any evidence of sulfide. SEM-EDS analysis of the copper pipe pits showed small amounts of sulfur (**Table 2**) but this was likely in the form of sulfate. The primary elemental composition of all pits was about 60% copper and 30% oxygen, by weight, indicating that they were probably a copper oxide. Small amounts of other elements were present, but the most interesting of these is aluminum. Recent research has shown that aluminum over 0.5% can catalyze copper pitting in very clean waters with a pH above 9 and with free chlorine[2,3].

Table 2: Summary of SEM-EDS Data from Pit Analysis

Pipe ID	Average Elemental Weight %										
	Cu	O	Si	S	Al	Cl	Ca	C	Fe	Mg	Mn
A	66.1	26.9	5.5	2.9	0.7	0.6	0.1	12.4			
B	63.8	30.8	2.9	1.6	1.2	0.1			0.5		
C	59.8	36.6	5.1	1.4	0.5	0.4	0.1				
D	62.7	24.5	10.8	0.4	1.5	0.6	0.4		0.5		
H	65.6	29.4	2.2	1.8	1.2		0.2		1.1	2.1	0.5

Data from the ICP-MS analysis of three pits (**Table 3**) also indicated that the primary element in all the pits was copper, with trace amounts of aluminum and silicon. It should be noted that all the mass was not recovered due to the fact that ICP-MS is not suitable for measuring elements such as oxygen, hydrogen, and carbon.

Copper pipe wall thickness measurements fell just below the normal range for Type M copper (**Table 4**). The 3 readings for each pipe ranged between 81-91% of the ASTM specification. Given that the pipes were 20-50 years old, they were not defectively thin.

Table 3: Summary of ICP-MS Data from Pit Analysis

Element	Pipe ID		
	B	D	F
sodium	4.2	2.3	1.9
magnesium	0.2	0.3	0.7
aluminum	4.3	2.6	7.0
silicon	36.4	44.5	95.2
phosphorus	2.1	2.0	1.9
calcium	1.1	0.7	1.5
copper	4,767.5	2,239.4	2,922.5
tin	0.3	0.1	0.3
lead	1.6	0.3	0.9
total weight recovered =	4,818	2,292	3,032
original weight of pit =	8,600	3,700	5,300
% of pit mass recovered =	*56.0%*	*62.0%*	*57.2%*

Table 4: Wall Thickness Measurement Summary

Pipe ID	Size	Wall Thickness (inches)						Tolerance
		Reading 1	Reading 2	Reading 3	Average	ASTM B-88	% of ASTM	
A	1"	0.031	0.031	0.031	0.031	0.035	88.6%	0.004
B	1"	0.030	0.031	0.030	0.030	0.035	86.7%	0.004
C	3/4"	0.028	0.028	0.027	0.028	0.032	86.5%	0.003
D	1"	0.032	0.032	0.032	0.032	0.035	91.4%	0.004
E	3/4"	0.028	0.028	0.029	0.028	0.032	88.5%	0.003
F	1"	0.029	0.028	0.028	0.028	0.035	81.0%	0.004
G	1"	0.033	0.030	0.032	0.032	0.035	90.5%	0.004
H	1/2"	0.024	0.023	0.023	0.023	0.028	83.3%	0.003

A review of the historical water quality data shed some light on the copper pitting issue. In over 10 years of dedicated research, the Edwards research group has only been able to reproduce copper pitting in a laboratory setting with water that exhibited these characteristics: high pH (9.0 or greater), low alkalinity, and high chlorine concentrations (see Sarver et al. for details[2]). A close look at the pH data for water leaving the Folsom WTP shows that the pH increased from about 7.5 prior to 2017 to around 9.0 beginning in summer/fall of 2017 (**Figure 1**). Additionally, pH exceeded 9.0 on numerous days after this change, and frequently exceeded 9.2. These conditions have made the water at Folsom a candidate for copper pitting based upon our laboratory experience, especially given the pristine condition of Folsom surface water and limited amounts of alkalinity and hardness. Any impurities present on the older copper pipes in this study cannot really explain a sudden outbreak of leaks as impurities are present on all copper pipes. Ironically, the higher pH that is desirable to reduce corrosivity for lead and copper under the EPA’s LCR can also sometimes change the type of copper corrosion in a manner that contributes to unexpected leaks.

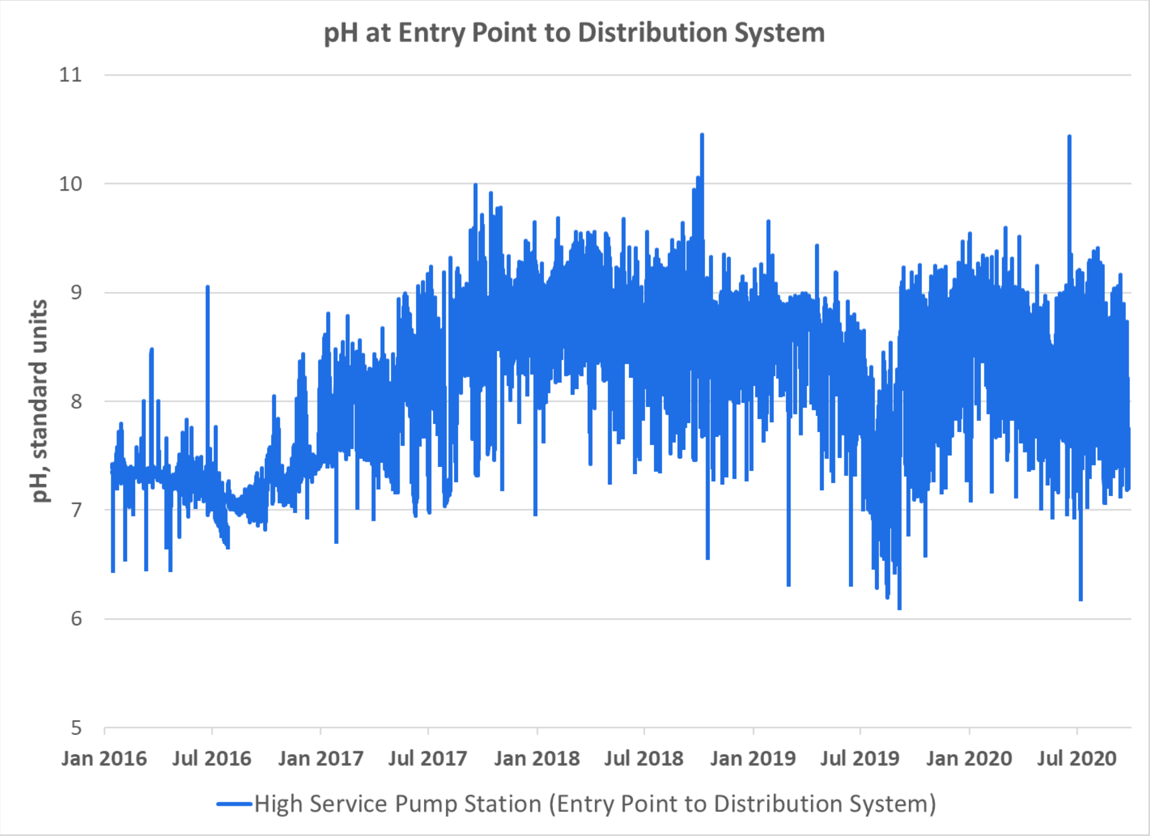

Figure 1 – Historical pH data for Folsom WTP

CONCLUSIONS AND RECOMMENDATIONS

Our findings from this study indicate that pH adjustments based on the LSI to reduce corrosivity for general lead and copper corrosion, which complies with the EPA’s LCR, could have contributed to conditions that initiated copper pitting corrosion. The lag of about 18-32 months between the pH change and the first reports of pinholes is in the range of expectations. (As an aside, if pH had consistently been controlled around 8.5, in all likelihood pitting would still have occurred eventually, but at a later date and a lower frequency of leaks.) In our laboratory studies and in one field test, dosing of an orthophosphate corrosion inhibitor dramatically reduced the incidence of pipe leaks after a period of a few months.

REFERENCES

1. Feigl, F., and V. Anger. Spot Tests in Inorganic Analysis. Elsevier Publishing Company, New York (1972).

2. Sarver, E., Dodson, K., Scardina, R.P., Lattyak-Slabaugh, R., Edwards, M., and C. Nguyen. Copper Pitting in Chlorinated, High-pH Water. ***JAWWA***. V. 103, No. 3, 86-98 (2011).

3. Rushing, J.C., and Edwards, M. Effect of Aluminum Solids and Chlorine on Cold Water Pitting of Copper. Corrosion Science. V. 46, 3069-3088 (2004).

APPENDIX 1: Photographs of Interior Surfaces of Copper Pipes

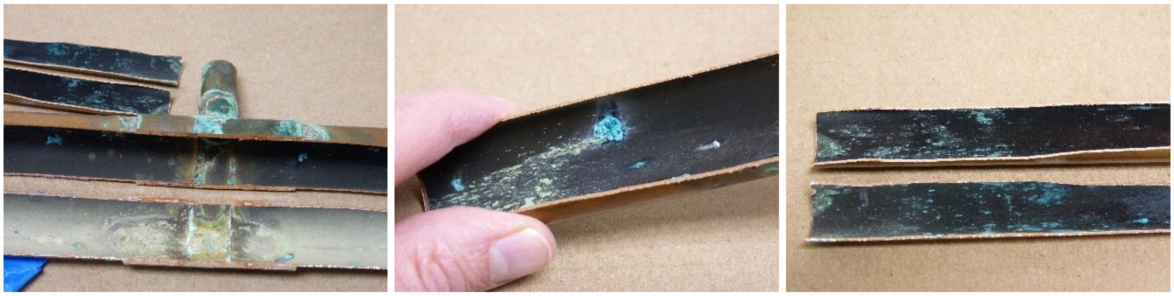

Figure A.1 – Pipe A

Figure A.2 – Pipe B

Figure A.3 – Pipe C

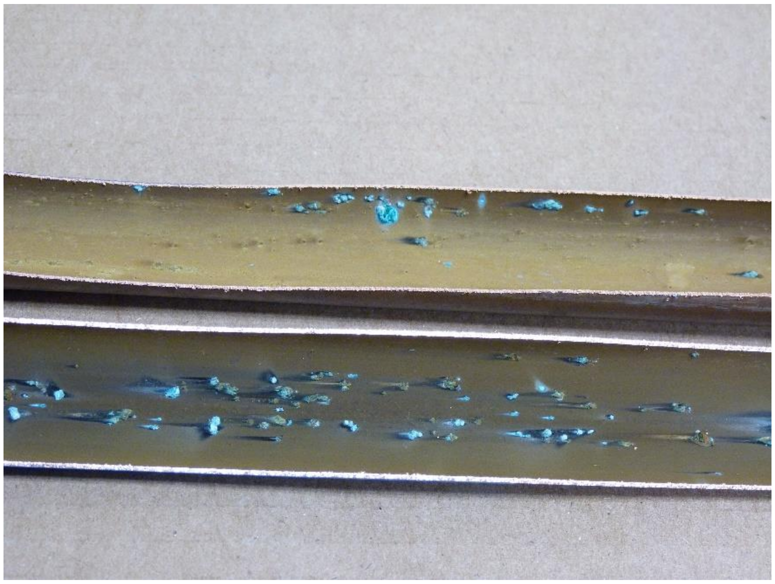

Figure A.4 – Pipe D

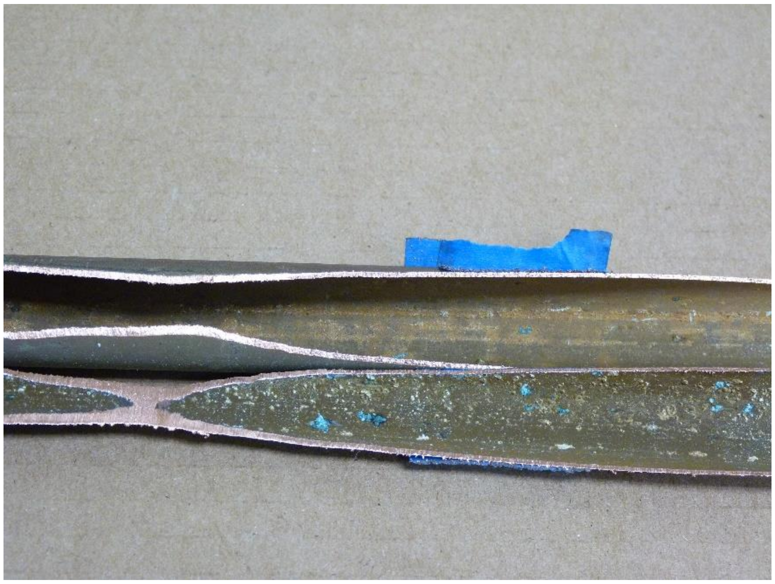

Figure A.5 – Pipe E

Figure A.5 – Pipe F

Figure A.5 – Pipe G

Figure A.5 – Pipe H

APPENDIX 2: Individual SEM-EDS Readings

Pipe ID	**Elemental Weight %**										
	Cu	**O**	**Si**	**S**	**Al**	**Cl**	**Ca**	**C**	**Fe**	**Mg**	**Mn**
Folsom 'A'	58.7	32.9	6.2	1.4	0.8						
	88.9	9.8			0.7	0.6					
	63.7	35.2		0.5	0.6						
	47.8	40.5	11.3		0.5						
	55.9	34.5	1.0	7.9	0.7						
	85.3	13.9			0.8						
	70.5	23.9	3.1	1.8	0.7						
	54.7	33.0	10.9	0.5	0.8		0.1				
	48.7	32.4	0.7	5.3	0.4			12.4			
	86.7	12.7			0.6						
average =	*66.1*	*26.9*	*5.5*	*2.9*	*0.7*	*0.6*	*0.1*	*12.4*			
Folsom 'B'	68.7	27.7	1.1	0.7	1.6	0.1					
	73.6	25.5	0.2		0.6						
	63.2	28.4	3.2	1.7	3.3	0.2					
	64.4	33.8	0.4	0.2	1.1	0.1					
	51.1	39.3	7.1	1.6	1.0						
	47.6	42.6	4.3	4.9	0.6						
	86.5	5.6	6.1	0.3	1.0				0.5		
	55.6	43.4	0.5		0.6						
average =	*63.8*	*30.8*	*2.9*	*1.6*	*1.2*	*0.1*			*0.5*		
Folsom 'C'	54.6	41.6	3.0	0.3	0.6						
	46.5	40.6	12.3	0.4			0.1				
	51.3	47.9		0.3	0.5						
	66.4	33.1	0.1		0.4						
	62.6	35.1		1.8	0.5						
	79.8	18.9		0.4	0.6	0.4					
	60.6	38.7		0.2	0.5						
	56.7	36.7		6.2	0.4						
average =	*59.8*	*36.6*	*5.1*	*1.4*	*0.5*	*0.4*	*0.1*				
Folsom 'D'	70.9	22.0	6.4		0.6		0.1				
	66.2	30.3	3.1		0.4						
	47.8	33.5	17.6	0.4	0.7		0.2				
	75.1	15.2	8.7		0.9		0.1				
	53.6	28.9	13.9		2.3	0.3	0.6		0.4		
	93.6	3.9	0.9		0.7	0.9					
	46.7	34.4	16.5		2.0		0.4				
	70.1	18.2	8.9		2.0	0.5	0.3				
	40.1	33.7	21.0		3.6		0.9		0.6		
average =	*62.7*	*24.5*	*10.8*	*0.4*	*1.5*	*0.6*	*0.4*		*0.5*		
Folsom 'H'	64.0	31.3		3.6	1.1						
	62.8	29.7		6.4	1.0						
	61.5	37.5		0.2	0.7						
	65.4	28.5	2.7	0.3	1.4				0.5	1.1	
	69.6	26.6	1.9	0.3	1.6						
	67.4	23.0	2.5	0.1	1.4		0.2		1.6	3.1	0.5
	68.3	29.0	1.8		0.9						
average =	*65.6*	*29.4*	*2.2*	*1.8*	*1.2*		*0.2*		*1.1*	*2.1*	*0.5*