Technical Memorandum

To:	Marcus Yasutake (City of Folsom)
From:	Pierre Kwan, Beth Mende, James Keegan (HDR)
Project:	Pinhole Copper Leak Investigation
Date:	12/7/2020
Subject:	Pinhole Copper Leak Investigation Summary Memorandum

1.0 Introduction and Purpose

The City of Folsom (City) began receiving reports of pinhole water leaks in local residential and business copper pipes throughout the City beginning in the month of July 2020 and are continuing to occur throughout the City to date. Over 1,300 pinhole leaks have been reported throughout the City as of November 2020. The City retained HDR to review the City's historical water quality data and perform a corrosivity analysis to investigate the issues related to the ongoing copper pinhole leaks occurring in customers' premise plumbing and to develop recommendations to prevent and significantly slow pinhole leaks from occurring. This technical memorandum (TM) summarizes the City's water quality and water corrosivity analysis as part of the pinhole leak investigation.

2.0 Copper Pitting Corrosion

Copper corrosion is categorized by either uniform or localized corrosion. Uniform corrosion is when corrosion is found to occur for most, if not all, of the wetted premise plumbing. In contrast, localized corrosion typically appears at random in premise plumbing and can typically be distinguished based on the water type in which it occurs and based on the morphology on the random pits in the plumbing wall.

There are four main types of pitting that take place in copper plumbing, three based on interactions between the water and metal surface and one based on bacteria. These pitting types include:

- Type 1 Pitting – typically associated with cold (<40 deg. C, <104 deg. F), hard, well waters with pH between 7 and 7.8 containing high sulfate relative to bicarbonate.
- Type 2 Pitting – typically occurs in hot (>60 deg. C, >140 deg. F) water piping systems with pH levels below 7.2 with high sulfate relative to bicarbonate.
- Type 3 Pitting – typically associated with cold, soft waters with a pH greater than 8.0 and low alkalinity.
- Microbial pitting – typically associated with biological growth inside the pipe and typically associated in stagnant waters with periods of little to no chlorine.

2.1 Causes of Pinhole Leaks

2.1.1 Water Quality

Water quality can play a large role in pitting corrosion of copper. Establishing the main cause of the pinhole leak in a distribution system can be complicated and dependent of multiple water quality parameters and 'favorable' conditions for corrosion to happen. Some of the most common water quality parameters that come into play when investigating pinhole leads include pH, alkalinity, free chlorine, chloride, sulfate, hardness, temperature and dissolved organic carbon. The City's water quality, as it related to copper corrosion, is discussed in Section 4.0 of this TM.

2.1.2 Copper Plumbing Material

Copper piping type is identified by its wall thickness. The inner diameter of the copper plumbing types is representative of the wall thickness. The service conditions, application, and installation are some of the factors that impact what type of copper plumbing is selected. There are three common copper plumbing materials that are used in construction:

- Type K – Type K copper piping has the thickest walls and is used in a variety of different applications in the construction industry.
- Type L – Type L copper piping has thinner walls that Type K piping, but thicker than TypeM piping. Type L copper plumbing is the most common type of copper plumbing and can be used in many more applications that Type K.
- Type M - Type M piping has the thinnest piping and was commonly used in domestic water systems. Type M copper piping is no longer allowed by plumbing codes in all areas or applications though older buildings may still have it in service.

Appendix A shows the most recent leak report as of October 22, 2020. The majority of the copper pinhole leaks were found in the City's Pressure Zone 1, Zone 2, and Zone 3. The majority of the housing stock in these zones was constructed prior to the 2000's with most of the construction in those areas occurring in the 1970's, 1980's and 1990's where copper piping was more commonly used in construction. Further, Type M copper piping was the most affordable piping material used in those timeframes and would indicate that the copper piping had thin wall thicknesses, which could increase the occurrence of corrosion and occurrence of pinhole leaks in piping. The City pulled copper piping samples from the areas impacted by the copper pinhole leaks. A corrosivity analysis was performed on the samples and is discussed in Section 5.0 of this TM.

3.0 Water System Background

The City receives all of its drinking water from Folsom Lake. Folsom Lake water is treated at the 50 million gallon per day (MGD) Folsom Water Treatment Plant (WTP) before being conveyed through the distribution system to the City's customers. The City's treatment process consists of rapid mix facilities, two parallel processes including 15 MGD conventional flocculation sedimentation basin and two 20 MGD Actiflo high rate clarification units, and conventional dual media filters. The WTP's chemical feed systems include aluminum chlorohydrate (ACH) for coagulation, sodium hypochlorite for disinfection and lime addition to adjust the finished water pH to a target of 8.0 to 8.7 for corrosion control based on the results of the Langelier Saturation Index (LSI).

The City utilizes pump stations, reservoirs, pressure reducing valves, flow control valves and pipelines to convey water through their distribution system to the City's seven main pressure zones. Table 1 presents the City's distribution system reservoirs that serve the City's seven major pressure zones.

Table 1. Reservoirs and Pressure Zones Served

Pressure Zone Served	Reservoir
Zone 1	South
Zone 1A	Nimbus
Zone 2	Tower; East
Zone 3	Foothills; Cimmaron
Zone 4	Broadstone
Zone 5	Carpenter Hill
Zone 6	Carpenter Hill

4.0 Water Quality Analysis and Data Review

The City monitors water quality at the WTP, system entry point and throughout the distribution system. This section reviews the City's water system and historical water quality data with a focus on the parameters that are important for copper plumbing corrosion including, pH, alkalinity, free chlorine, chloride, sulfate, hardness, temperature and dissolved inorganic carbon (DIC).

4.1.1 Finished Water Quality

The City monitors water quality throughout the treatment process and at the system entry point. The pH of both the raw water and finished water is monitored continuously. The lime feed is adjusted periodically based on the pH measurements to keep the pH between the City's target of 8.0 to 8.7. Table 2 presents the water quality data from quarterly grab samples collected at the distribution system entry point between the years 2010 and 2020.

Based on the data collected, the average pH levels fell above the City's finished water pH target between 8.0 and 8.7, ranging from 8.2 to 9.3, with an average pH of 8.8. Alkalinity in the grab samples taken was low, ranging from 18 to 35 mg/L as $CaCO_3$, with an average of 25 mg/L as $CaCO_3$, which impacts the buffering capacity and ability to maintain pH throughout the distribution system. The samples taken had low chloride and sulfate level and average hardness of 23 mg/L as $CaCO_3$, which would classify the water as being relatively soft. Additionally, the samples had an average chlorine residual of 1.4 mg/L. Initial observation of water quality data indicates water quality that could be categorized under Type 3 copper pitting with a pH greater than 8.0, low alkalinity, soft water with a chlorine residual that could lead to copper pitting in plumbing.

Table 2. Finished Water Quality Grab Samples at Distribution System Entry Point (2010 – 2020)

Parameter [1]	Units	Min	Average	Max
pH	standard units	8.2	8.8	9.3
Alkalinity	mg/L as $CaCO_3$	18	25	35
Chlorine Residual	mg/L	1.31	1.4	1.64
Temperature	DegC	17.7	21.2	23.4
Total Dissolved Solids (TDS)	mg/L	24	47	70
Hardness	mg/L as $CaCO_3$	12	23	33
Chloride	mg/L	3.3	5.3	9.9
Sulfate	mg/L	0.5	2.3	11
Calcium	mg/L	3.5	6.2	9.3
Magnesium	mg/L	1.1	2.0	4.8

Notes:

1. Data from quarterly water grab samples from 2010-2020.

4.1.2 Distribution Water Quality

The City monitors water quality throughout the distribution system including monitoring of its reservoirs for chlorine, pH, temperature and conductivity on a daily basis. As noted earlier, the majority of the copper pinhole leaks found through October 22, 2020 has been in the City's Pressure Zones 1, 2, and 3. Table 3 presents the average pH levels in the City's reservoirs for the past 5 years.

Table 3. Average Reservoir pH Levels (2015-2020)

Pressure Zone	Reservoir	Average pH (mg/L)					
		2015	2016	2017	2018	2019	2020
1A	Nimbus	7.74	7.38	8.36	8.74	9.08	8.81
1	South	7.70	7.60	8.30	8.63	9.00	8.93
2	East	7.78	7.65	8.18	8.38	8.53	8.42
	Tower	7.79	7.70	8.20	8.45	8.53	8.41
3	Cimmaron	7.79	7.78	8.17	8.93	8.61	8.44
	Foothills	7.76	7.65	8.22	8.46	8.58	8.41
4	Broadstone	7.73	7.64	8.18	8.72	8.53	8.31
5	Carpenter Hill	7.53	7.12	7.94	8.58	8.68	8.39
6	Carpenter Hill	7.71	7.77	8.20	8.41	8.67	8.67

Figure 1 presents the Zone 1 pH levels in the water exiting from the City's South Reservoir. The trend shows similar pH levels in the reservoir from 2015 and 2016 with average pH levels ranging from 7.6 to 7.7. A change in pH levels is noticed starting in 2017 where the pH ranges began to increase to an average pH of 8.3, nearly a 0.6 increase in pH. The trend continues into 2018, where the average pH increased to approximately 8.76. In 2019, the data shows much more fluctuation in the reservoir water pH levels as they increase to between 9.0 and 9.5, with an annual average of 9.0, an overall average increase of 1.3 since 2015.

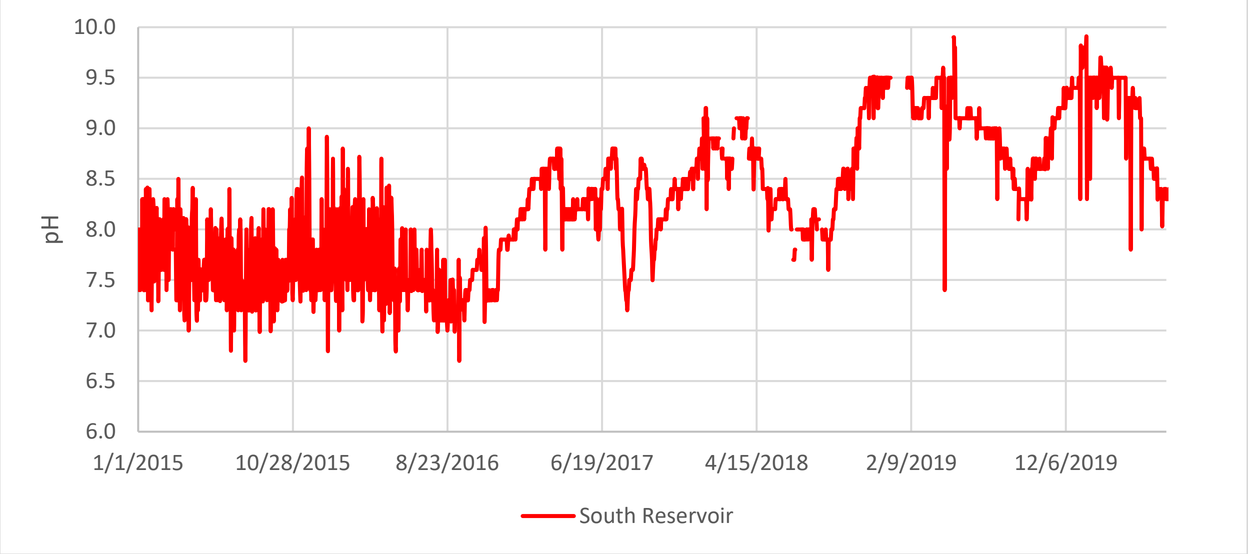

Figure 1. pH Levels in Zone 1 (2015-2020)

Figure 2 presents the water pH from the City's Tower and East Reservoirs that serve Zone 2. The trend shows similar pH levels in both reservoirs with annual average pH levels the same in both reservoirs from year to year. Similar to South Reservoir (Zone 1), a change in pH levels is noticed starting in 2017 where the average pH ranges began to increase to an average pH of 8.2, a 0.4 increase in pH. The trend continues into the following years, where the annual average pH continued increase. In 2019, the annual average was 8.53, which was less than that of South Reservoir in Zone 1, but still an overall increase of 0.7 in average pH level since 2015.

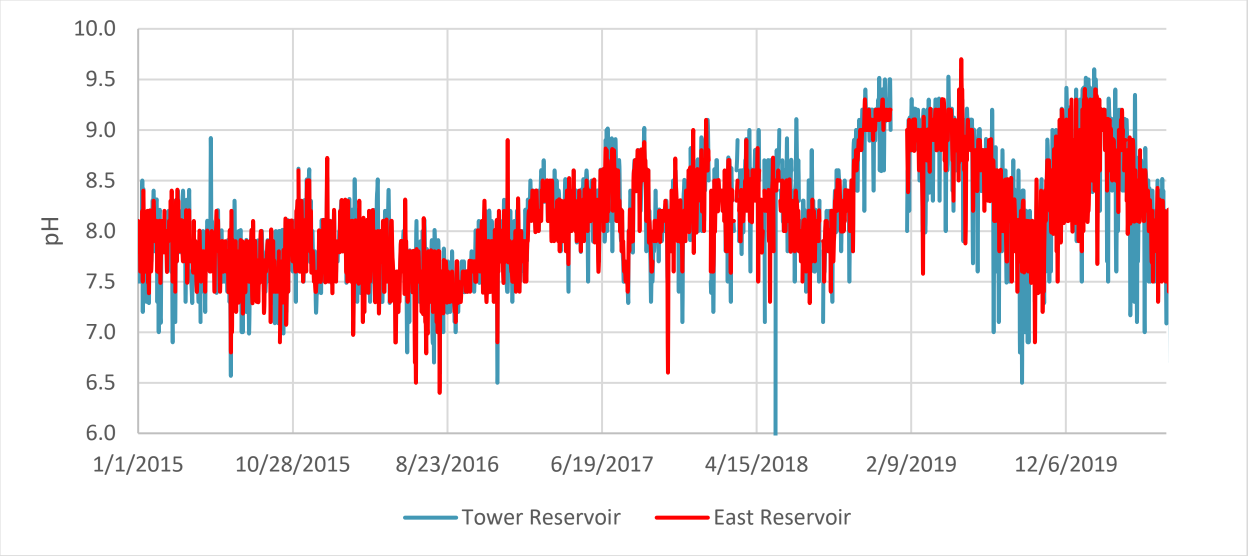

Figure 2. pH Levels in Zone 2 (2015-2020)

Figure 3 presents the water pH from the City's Foothills and Cimmaron Hills Reservoirs that serve Zone 3. The trend shows similar pH levels in both reservoirs with annual average pH levels the same in both reservoirs from year to year, and very similar to that of the reservoirs in Zone 2 in Figure 2. Similar to that of the pH trends in Zone 1 and 2, there is an increase in pH after 2017 continuing into 2019, with an overall increase of around 0.8 in pH from 2015 to 2019.

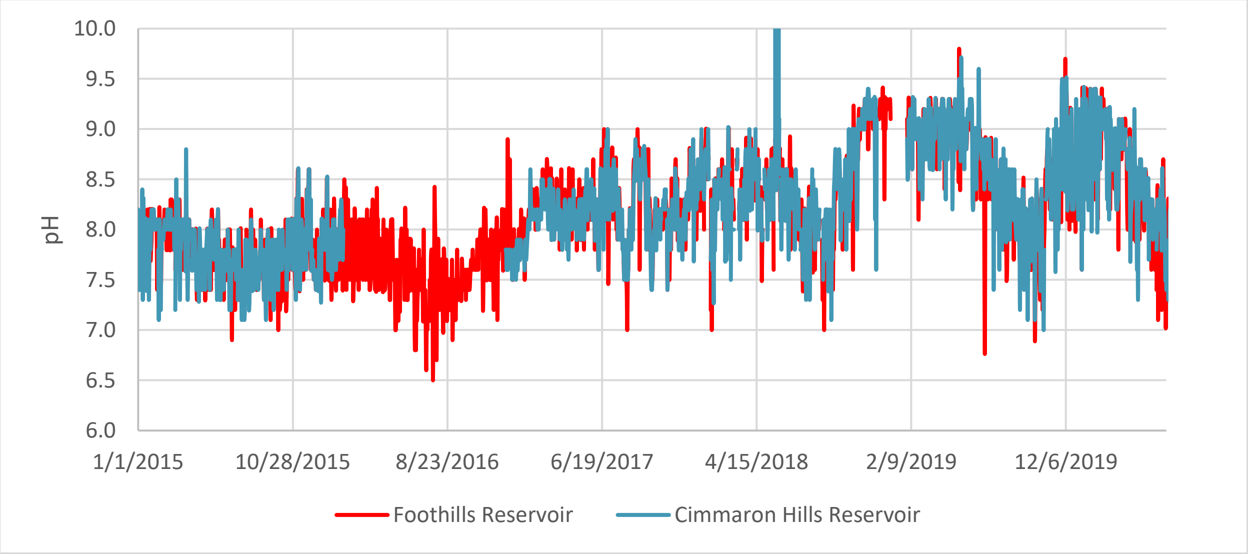

Figure 3. pH Levels in Zone 3 (2015-2020)

Figure 4 and Figure 5 presents the water pH from the City's Reservoirs that serve Zone 4 and Zone 5 and 6, respectively. Based on the pH data presented in Table 3, the average pH levels from year to year follow similar trends to Zones 2, 3 and 3 with a pH increase in 2017.

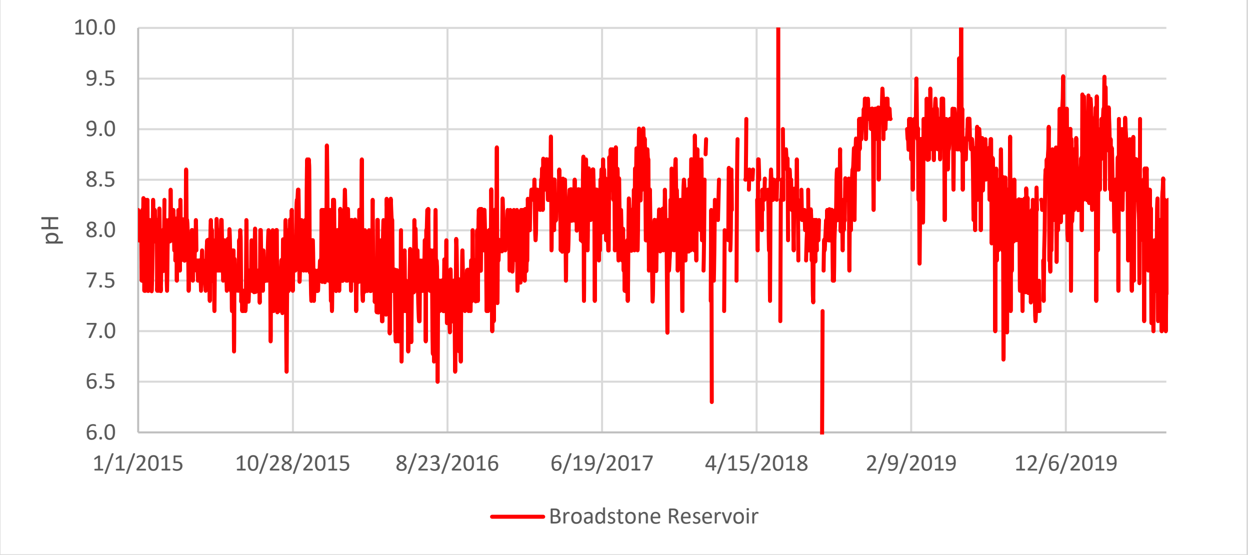

Figure 4. pH Levels in Zone 4 (2015-2020)

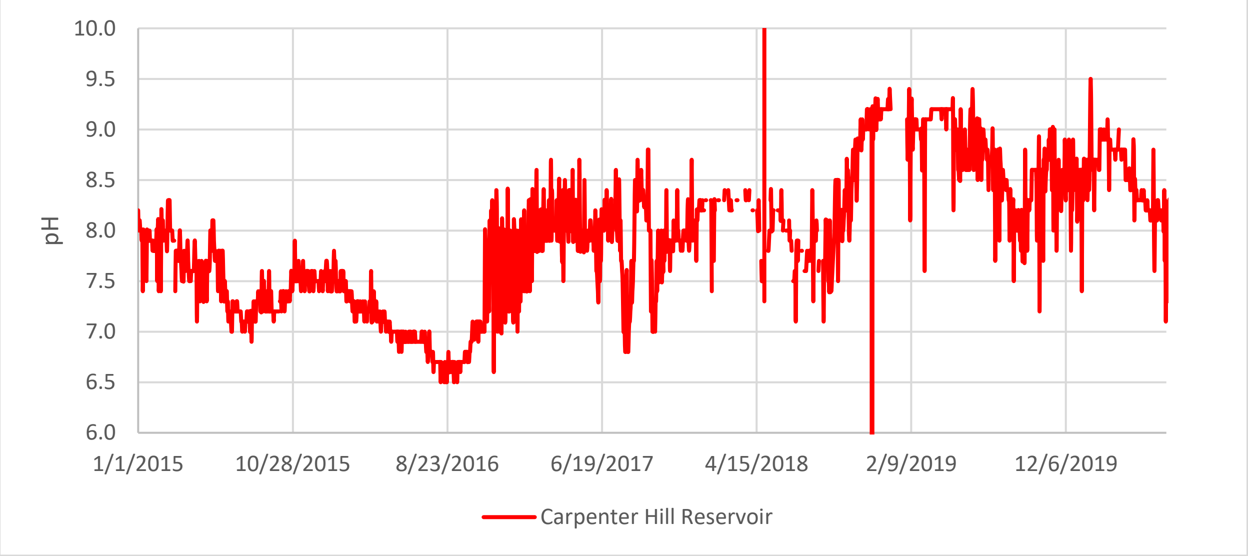

Figure 5. pH Levels in Zone 5 and Zone 6 (2015-2020)

Table 4 presents the distribution system chlorine residual exiting the City's reservoirs that serve each zone from 2015 to 2020. The data shows a trend of increasing average chlorine residuals through all of the City's reservoirs from 2015 to 2017. In 2018, the annual average chlorine levels decreased in all reservoirs and then began increasing again in 2018 and 2019. Zone 2 and 3 had the highest chlorine residuals during these years, averaging between 1.01 and 1.17 mg/L.

Table 4. Average Reservoir Chlorine Residual Levels (2015-2020)

Pressure Zone	Reservoir	Average Chlorine Residual (mg/L)					
		2015	2016	2017	2018	2019	2020
1A	Nimbus	0.79	0.79	0.90	0.75	1.02	0.84
1	South	0.42	0.55	0.67	0.54	0.67	0.63
2	East	0.85	0.87	1.02	0.82	0.93	0.89
	Tower	1.24	1.16	1.09	0.95	1.15	1.17
3	Cimmaron	0.96	1.09	1.03	0.92	1.06	1.02
	Foothills	0.89	0.90	1.05	0.92	1.01	1.01
4	Broadstone	0.44	0.53	0.68	0.69	0.77	0.78
5	Carpenter Hill	0.44	0.53	0.68	0.59	0.77	0.78
6	Carpenter Hill	0.49	0.55	0.71	0.65	0.77	0.83

1. 2020 water quality data only consists of the data from the months January through July.

After the pinhole leaks began being reported in July 2020, the City pulled water quality grab samples in locations near where the initial pinhole leaks were reported. Table 5 presents the sampling results from the July 2020 sampling event. The pH ranged from 7.6 to 8.8, with two samples measuring below pH 8.0. Alkalinity in the samples was low ranging from 30 mg/L as $CaCO_3$ to 37 mg/L as $CaCO_3$. The samples taken had low chloride and sulfate level and hardness values ranged from 27 to 34 mg/L as $CaCO_3$ (relatively soft). Additionally, the samples had chlorine residuals ranging from 0.75 to 1.27 mg/L.

Table 5. Sampling Event Water Quality (July 2020)

Sample Date	Sample Description	Pressure Zone	pH (s.u.)	Chlorine Residual (mg/L Cl_2)	Alkalinity (mg/L as $CaCO_3$)	Total Dissolved Solids (mg/L)	Copper (mg/L)	Hardness (mg/L as $CaCO_3$)	Chloride (mg/L)	Sulfate (mg/L)	Temp. (DegC)	DIC (mg C/L)[1]
7/24/2020	Brock Circle	Zone 2	8.6	1.07	34	55	<0.05	32	4.4	2.2	18.2	8
7/24/2020	Riley Court	Zone 2	8.2	0.75	33	62	<0.05	31	4.5	2.1	18.1	8
7/24/2020	Bindell	Zone 2	8.3	1.09	34	63	<0.05	31	4.3	2.1	17.9	8
7/24/2020	Russler	Zone 2	8.1	1.27	33	55	<0.05	30	4.4	2.1	18.1	8
7/24/2020	Moylan	Zone 2	8.1	1.16	34	59	<0.05	31	4.3	2.2	18.1	8
7/24/2020	Newmark	Zone 2	8.1	1.01	33	59	<0.05	30	4.4	2.2	18.8	8
7/24/2020	Parsons	Zone 2	8.3	1.19	35	53	<0.05	31	4.3	2.2	19.5	8
7/24/2020	Kilsby	Zone 2	7.9	1.11	32	53	<0.05	28	4.4	2.1	19	8
7/24/2020	Big valley	Zone 2	7.6	1.05	30	52	<0.05	27	4.5	2.1	18.8	8
7/24/2020	Lisa Wood	Zone 2	8.8	1.26	37	57	<0.05	34	4.7	2.1	19.2	9
7/24/2020	Fausset	Zone 3C	8.6	1.06	35	56	<0.05	33	4.6	2.1	19.8	8

Notes:

1. DIC was calculated based on sample pH and alkalinity.

4.1.3 Lead and Copper Rule Compliance

Water samples are collected from home faucets in the City to monitor copper as part of the Lead and Copper Rule (LCR) compliance. Table 6 summarizes the lead and copper results from 1995 through 2020. All of the samples are first-draw samples that were taken after the water was left standing in the faucet and adjacent plumbing for at least six hours. The United States Environmental Protection Agency (USEPA) has set an action level for lead and copper in first-draw samples of 0.015 mg/L and 1.3 mg/L, respectively. The 90th percentile concentration of lead and copper is compared to the action levels to determine compliance. Based on the LCR sampling results, the City has been well below the action levels and has always been in compliance with the LCR since the rule was promulgated in 1991.

Table 6. Lead and Copper Rule Copper Sampling Results Summary

Sampling Year	Lead (mg/L) Action Level: 0.015 mg/L	Copper (mg/L) Action Level: 1.30 mg/L
	90th Percentile	90th Percentile
1995	0.009	0.16
2005	0.003	0.15
2008	0.003	0.36
2011	ND	0.16
2014	ND	0.23
2017	ND	<0.05
2020	ND	<0.05

5.0 Corrosion Analysis

5.1 Background

On September 30, 2020, a field engineer from HDR visited three residences in the City's service area where pinhole leaks had occurred. The purpose of the visits was to perform onsite water corrosivity testing, collect water samples for laboratory testing, and to collect samples of failed copper tubing for evaluation. Three samples were taken and are identified in Table 7. The overall goal of this testing was to provide additional insight on the likely cause for the copper tubing pinhole leaks.

Table 7. Copper Piping Samples

Sample ID	Sample Location	Pressure Zone
Larkhall	Larkhall Circle	Zone 5
Rathbone	Rathbone Circle	Zone 2
Chalcedony	Chalcedony Court	Zone 3F

5.2 Water Chemistry and Copper Tubing Analyses

5.2.1 Methods

The temperature, and dissolved oxygen content were measured on each water sample in-situ using a HACH HQ40d field unit. pH was measured on each sample using an Oakton AO-35423-01 EcoTestr. pH was measured at the time of collection and again at ten minutes after collection and on one sample pH was repeated at 20 minutes. Hach 2745050 Free and Total Chlorine Test Strips were used to evaluate total and free chlorine in each sample. Standard Method 4500-CO2 was used to determine dissolved carbon dioxide and Standard Method 2320-B was used to determine alkalinity/bicarbonate. An additional 20-mL sample of water was titrated with 0.02 N sulfuric acid and bromcresol green/methyl red as an indicator to determine bicarbonate. Prior to onsite testing the water was run for approximately five minutes before sampling to ensure that the water chemistry results were consistent with the water in the City's system at that location. Testing was performed in the order listed above and testing at each location lasted 20-30 minutes. The test results are shown in the attached Table 1B in Appendix B.

The pH of each water sample was measured in the laboratory per Standard Method 4500-H+. An undiluted portion of the water samples was chemically analyzed for the major soluble salts commonly found in water per ASTM D4327, ASTM D6919, and Standard Method 2320-B1. The Ryznar Scaling Index was calculated for each of the water samples based on a combination of field and lab data. If field results were available they were used. For values such as calcium that were not determined in the field, lab results were used. Dissolved inorganic carbon was calculated based on the field bicarbonate results. The laboratory analysis was also performed under HDR laboratory number 20-0654LAB and the test results are shown in the attached Table 2B in Appendix B.

The three copper tubing samples were examined, which included visual inspection, photographic documentation, and pipe wall thickness measurements. Pipe wall thicknesses were measured after removing the burs from the ends of the tubing. Measurements were made with calipers. The tubing samples were split lengthwise using a band saw for inspection. A qualitative test for the presence of carbonate was performed on the corrosion product of one of the samples by applying a solution of hydrochloric acid to test for fizzing.

5.2.2 Results

Field Testing

The initial pH values measured in the field ranged from 8.4 to 9.8. This range is moderately to very strongly alkaline. Ten minutes after sampling the pH values were 8.0 in the Larkhall and Chalcedony samples and 8.9 in the Rathbone sample. After sitting twenty minutes, the Rathbone sample had a pH of 8.1. The reduction in pH is likely associated with residual hydroxide from lime treatment reacting with atmospheric carbon dioxide, which would result in a decrease in pH and an increase in bicarbonate.

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[1] American Public Health Association (APHA). Standard Methods of Water and Wastewater, 22nd ed. American Public Health Association, American Water Works Association, Water Environment Federation publication. APHA, Washington D.C., 2012.

The water temperature was 28.4 °C at Larkhall and Chalcedony residences and 24.3 °C at the Rathbone residence. Dissolved oxygen ranged from 8.11 to 7.84 mg/L. This results in a saturation range of 96 – 106 percent.

Total chlorine ranged from not detected (ND) to 1 mg/L and free chlorine was ND in all three samples. On average, HDR would have anticipated chlorine values to be slightly higher based on the proximity of the three residences to the treatment plant. It should be noted that these tests were measured with test strips making them only semi-quantitative. Consequently, these results are close to but may not be the exact residual chlorine levels at the time of sampling. The data is only used by HDR for the specific purpose of this investigation. The methodology and semi-quantitative accuracy of the resultant data is lower than the City's and State's regulatory compliance and reporting requirements (the City's monitoring and sampling equipment is of a higher standard and accuracy which meets State requirements).

Bicarbonate ranged from 7.3 mg/L in the Larkhall and Chalcedony samples and 24 mg/L in the Rathbone sample, which equates to 12 and 39 mg/L as $CaCO_3$. These values are typical for drinking waters coming from surface waters heavily influenced by snowmelt. The principal purpose of alkalinity for LCR compliance with such source waters is to adequately buffer drinking water to minimize pH variations as this water leaves the treatment plant and is transmitted through the distribution system. A general rule is to have alkalinities >25 mg/L as $CaCO_3$. Table 8 lists the drinking water alkalinities from nearby utilities using surface waters as well as utilities with comparable water qualities. As noted in Table 8Table 2, the average alkalinity in the City's water is 25 mg/L as $CaCO_3$. This is less than San Francisco, Sacramento, and the largest water utility drawing out of Lake Tahoe. However, this value is higher than Seattle, Washington, Portland, Oregon, and Vancouver, British Columbia. Note that Portland in the process of increasing their water alkalinity to a value that would match the City's to reduce lead corrosion while Vancouver is doing the same to reduce copper premise plumbing pinhole leaks. This benchmarking would indicate the City water alkalinity is comparable to other utilities and should not require adjustment.

Table 8. Alkalinities of Comparable Water Utilities

Utility	Surface Water Sources	Average Alkalinity (mg/L as $CaCO_3$)
San Francisco Public Utilities Commission	Hetch Hetchy Reservoir	51
City of Sacramento	Sacramento and American Rivers	30
Douglas County – Zephyr Cove	Lake Tahoe	35
Portland (OR) Water Bureau	Bull Run	11 (increasing to 25 by 2022)
Seattle Public Utilities	Cedar River, Tolt River	18 – 21
Metro Vancouver (British Columbia)	Seymour, Capilano, and Coquitlam Reservoirs	10 (increasing to 25 by May 2020)
Source: Respective 2020 Annual Consumer Confidence Reports		

Laboratory Testing

The pH values measured in the lab ranged from 7.5 to 7.6. This range is mildly alkaline. As mentioned above, the reduction in pH from the time of sampling is likely due to reaction between residual hydroxide from lime treatment with ambient carbon dioxide. The soluble salt content of the water samples was low.

Visual Inspection and Photo Documentation

During external inspection of the tubing samples a single pinhole was observed in each of the three samples. The rest of the external surface was unremarkable with no other observed corrosion or blemishes.

The internal inspection began with the collection of the samples when clearly elevated nodules of corrosion product were evident at each pinhole. A typical example of this can be found in Photo 7 below. Unfortunately, the delicate nodules broke free from the pipe surface during the tube sectioning process. Consequently, they are not visible in the micrographs below.

The interiors of the pipe samples all had greenish-greyish to greenish-blackish films which is consistent with observed copper oxides that form in high pH and low dissolved inorganic carbon (DIC).[2]

Pinholes were evident and can be observed inside of the remaining blue corrosion product. The morphology of the corrosion was predominantly pitting in nature rather general corrosion. In the Larkhall samples (Figure 6 and Figure 7) and Rathbone samples (Figure 8 and Figure 9), the pitting did not appear to have an association with the presence of flux or flux runs. However, the morphology of the corrosion on the Chalcedony sample (Figure 10 and Figure 11) indicates that flux

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[2] *Lytle, Darren A., and Schock, Michael R. Pitting Corrosion of Copper in Waters with High pH and Low Alkalinity, Journal AWWA, 100:3. American Water Works Association, 2008, pp., 115-129.*

could possibly be a contributing factor to pit initiation. This is evidenced by the streak of corrosion that runs through the pit, which could be consistent with a flux run. Common soldering flux contains ammonium chloride in a rosin base. Flux can contribute to corrosion because ammonium can be aggressive to copper and the rosin inhibits the formation of a protective scale. Figure 12 is a photo indicating an intact scale that had been removed.

Each of the pinholes are of a shape and morphology consistent with chemical corrosion and lacks the appearance typical of microbial corrosion (i.e. extensive surface pitting around pinhole and irregularity in the pinhole shape).

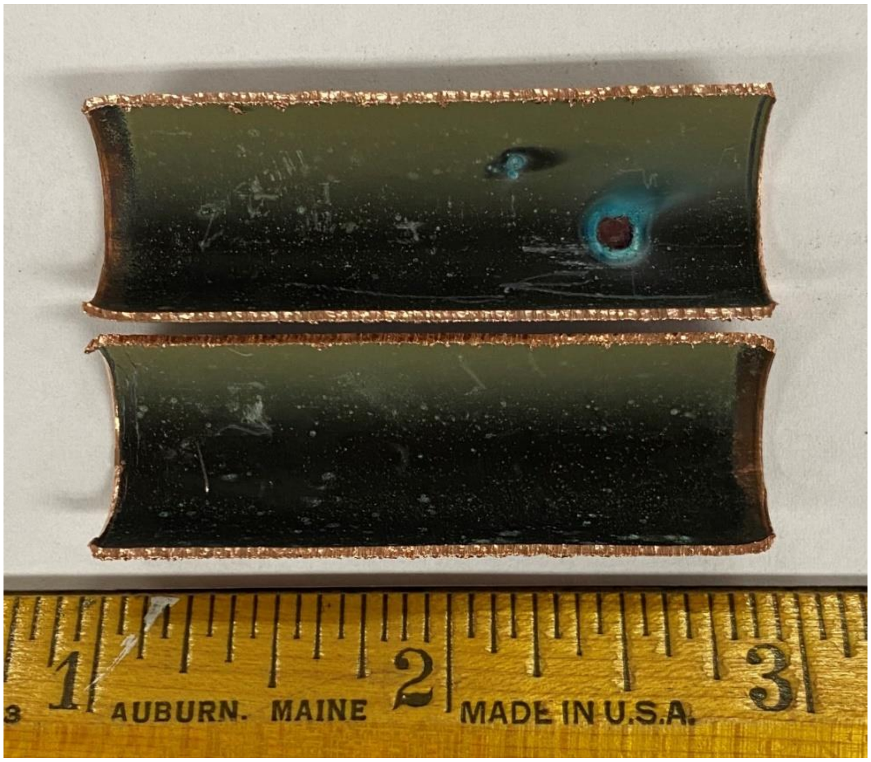

Figure 6. Tubing Sample from Larkhall Circle

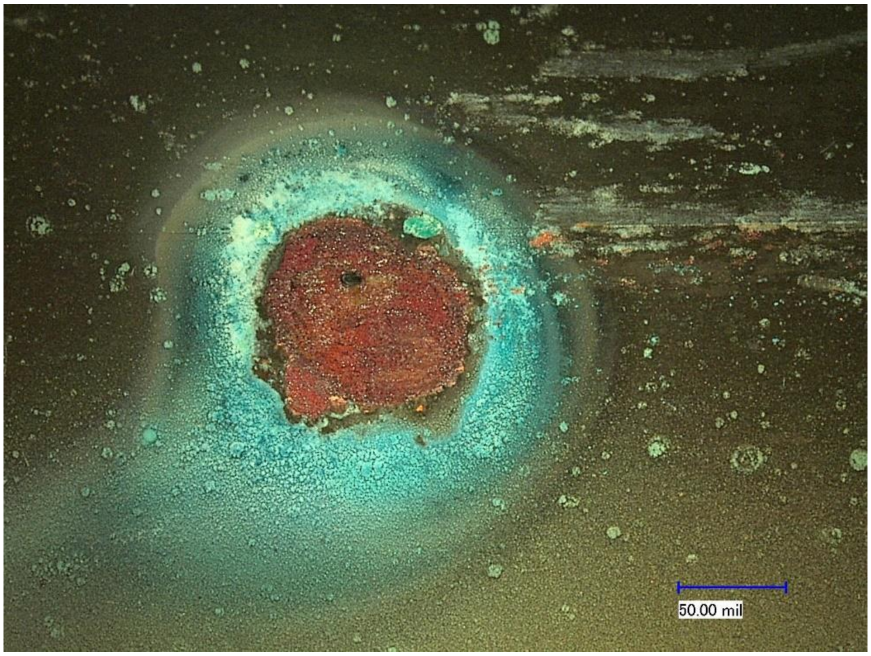

Figure 7. Close-up of Pit at Larkhall Circle

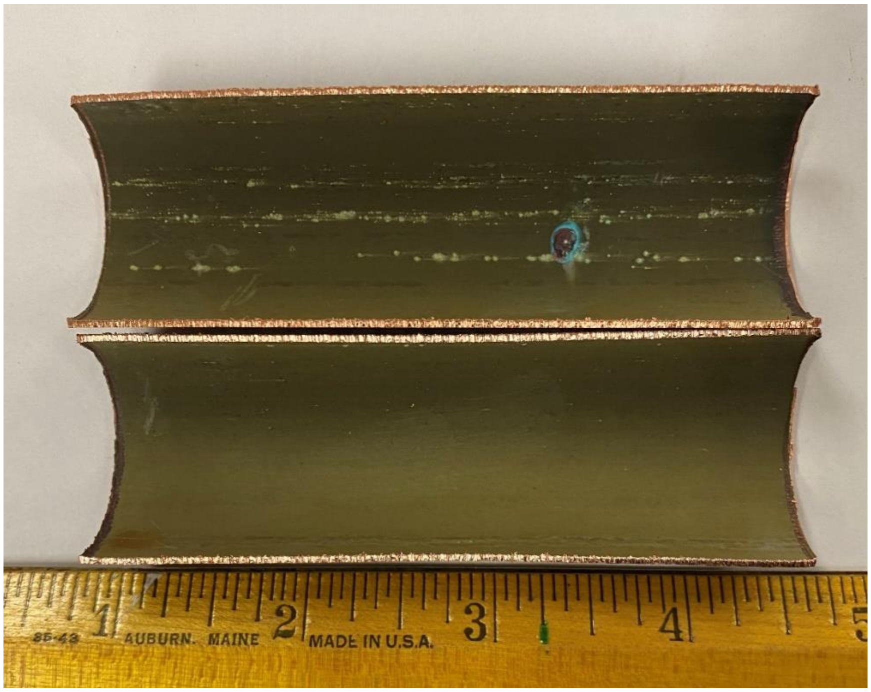

Figure 8. Tubing Sample from Rathbone Circle

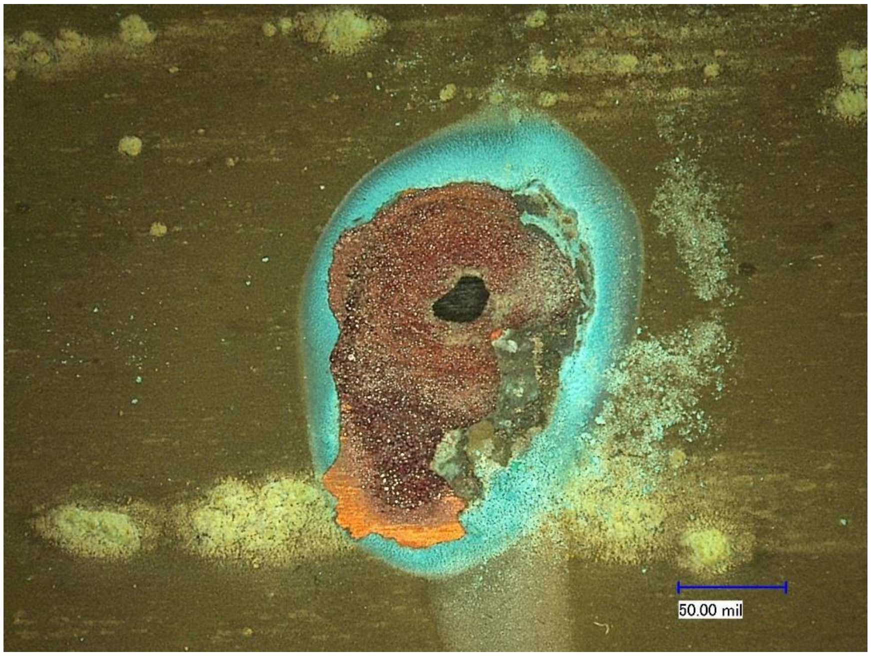

Figure 9. Close-up of Pit at Rathbone Circle

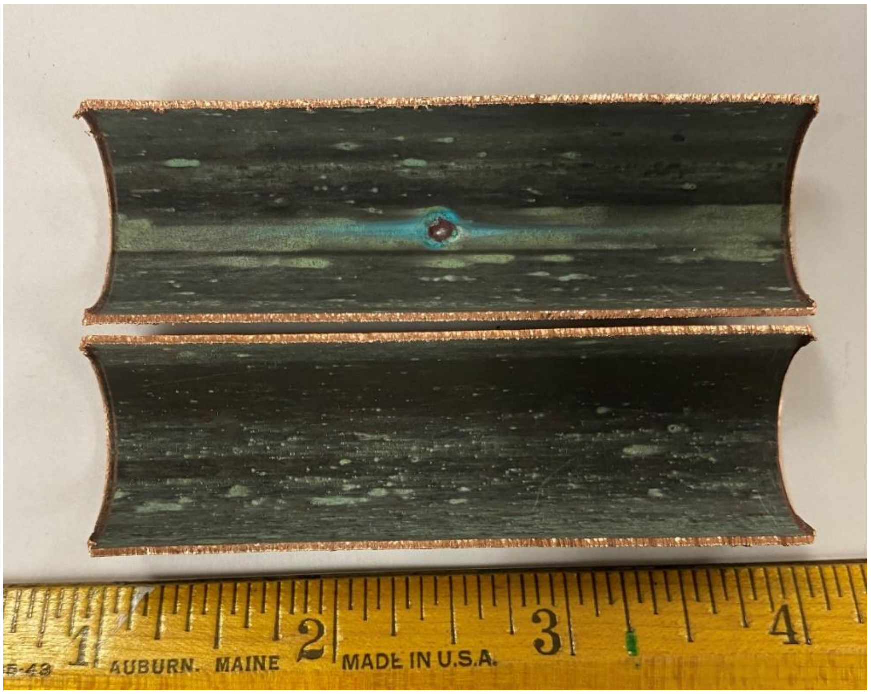

Figure 10. Tubing Sample from Pit at Chalcedony Court

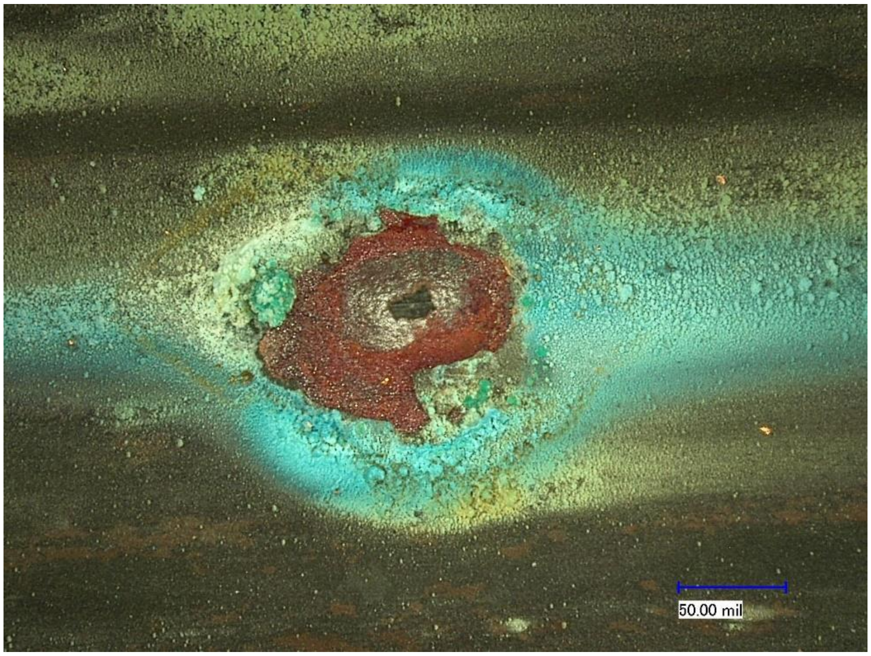

Figure 11. Close-up of Pit at Chalcedony Court

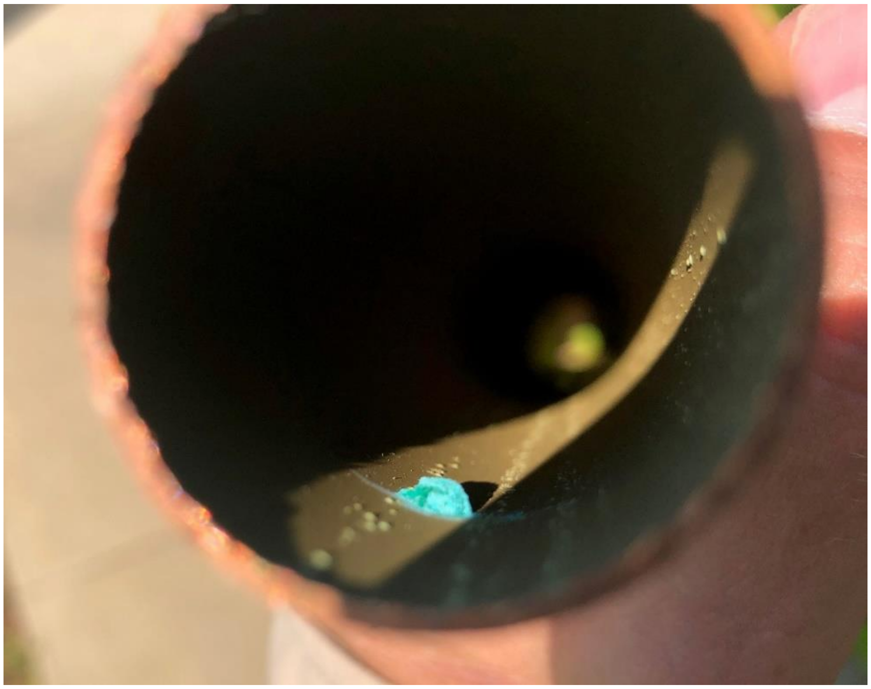

Figure 12. Intact Corrosion Product

Pipe Wall Thickness Measurements

Pipe wall thickness measurements are summarized in Table 9 below. The pipes are estimated to be Type M copper.

Table 9. Pipe Wall Thickness and Diameters

Sample ID	Nominal Diameter (inches)	Wall Thickness (mils)
Larkhall	½	28
Rathbone	1	32
Chalcedony	¾	35

Corrosion Product

Qualitative testing for carbonate salts in the corrosion product was performed by applying hydrochloric acid to the corrosion product to check for fizzing as carbonate is converted to carbon dioxide gas. This test was positive for the presence of carbonate. Combined with the bright turquoise coloration, the scale is mostly like malachite ($Cu_2(OH)_2CO_3$), a mixed corrosion scale commonly found in copper plumbing that has been exposed to a pH between 8.5 and 9.0 in water for at least several weeks. This scale is generally beneficial and protects the underlying copper metal. However, as a mixed scale, this mineral is prone to decomposition that then exposes metallic copper to water. This is why the presence of malachite does not mean copper pitting is occurring, but incidences of copper pitting often involve malachite. This decomposition risk is specific to malachite and does not occur with other minerals like copper oxides formed at lower pH or copper phosphate formed in the presence of orthophosphate in the water.

6.0 Conclusions and Recommendations

Based on the water quality review and corrosion analysis, there were a number of factors that could have contributed to the increased pinhole leaks that have manifested throughout the City. The City’s water quality contains low levels of alkalinity and minerals and can be classified as relatively soft, with relatively high pH levels, above 9 in some cases throughout the year, which indicates that the pinhole leaks could be associated with Type 3 cold water pitting corrosion. The presence of carbonate in the corrosion product is also consistent with Type 3 corrosion. This can especially occur at sites with impurities in the pipe material or at sites where particulate settled.

Based on the corrosivity analysis, it was confirmed that the likely corrosion mechanism of the tubing samples examined is primarily Type 3 cold water pitting corrosion with one of the three samples tested possibly having an association with a flux run. Type 3 copper corrosion could be accelerated by free chlorine concentrations greater than 1 mg/L. While the City's historic testing shows residual chlorine levels in the 1 mg/L range, HDR's measurements did not detect chlorine levels exceeding 1 mg/L. This concentration of free chlorine in the distribution system is typical for many drinking water utilities throughout the United States and is far below the State and Federal maximum allowable concentration of 4 mg/L.

Additionally, the main pressure zones experiencing pinhole leaks (Zones 1, 2 and 3) were constructed between 1970 and 1990, indicating that the plumbing used was likely copper plumbing. Based on the reservoir water quality data, the reservoir water quality is very consistent throughout the system, with varying chlorine residuals as water makes its way through the system. This could indicate that the pinhole leaks could continue into the future in other pressure zones if not changed. The homes in the City's other pressure zones are much newer and were constructed in the 2000's, meaning that they could have been constructed using different plumbing materials. However, if copper plumbing was used, it may be a similar timeframe before pinhole leaks began occurring in those zones in the future.

Orthophosphate has been found to be effective corrosion inhibitor and is commonly used to address the issues such as experienced by the City. Orthophosphate has been found to be effective at pH levels as high as 9.0 but with differing efficacy at different pH levels. For example, a 0.5 mg/L as PO_4 dose provides more corrosion inhibition at 7.2 to 7.8 and less (but still positive) inhibition at pH 8.0 to 8.4. While it is less effective at higher pH, published literature shows that its use in waters similar to the City's reduces copper corrosion compared to waters without it[3]. The literature documents that orthophosphate corrosion inhibitors can minimize uniform (non-pitting) corrosion on copper, copper alloys and lead bearing surfaces – it is increasingly employed as a copper corrosion control strategy. There is also growing evidence that the addition of even a modest dosage (0.5 to 1.0 mg/L as PO_4) is a viable strategy to inhibit those forms of copper pitting not related to erosion or plumbing fabrication defects.

The City has started using orthophosphate while maintaining a finished water pH target of 8.5. HDR recommends that orthophosphate usage and current pH targets be maintained for six months and to monitor pinhole leak occurrence. If the leak issue is resolved, then no further action is required. If the leaks continue, then HDR recommends that the City adjusting downwards and decreasing the pH target to 8.2 +/- 0.2 (range of 8.0 and 8.4) in the water leaving the plant. While the City's pH was higher than the established goal of 8.0 to 8.7 in the 2017 – 2020 timeframe, which likely was a contributing factor to the sudden increase of pinhole leaks throughout the City's system, the City has since made adjustments in October 2020 to bring the pH into the 8.0 to 8.7 range. These pH adjustments, while having an impact on plumbing corrosion (both initially negative and now positive), are allowed by State regulators for drinking water. HDR notes that at no time has the drinking water the City produced been out of compliance with all applicable regulations for cleanliness, purity, and aesthetics. In addition, the water quality has continuously met additional requirements that State regulators had established with regards to LSI as noted in Section 3.0.

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[3] *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems, EPA, 2016, pp., 47.*

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Appendix A. Pinhole Leak Report

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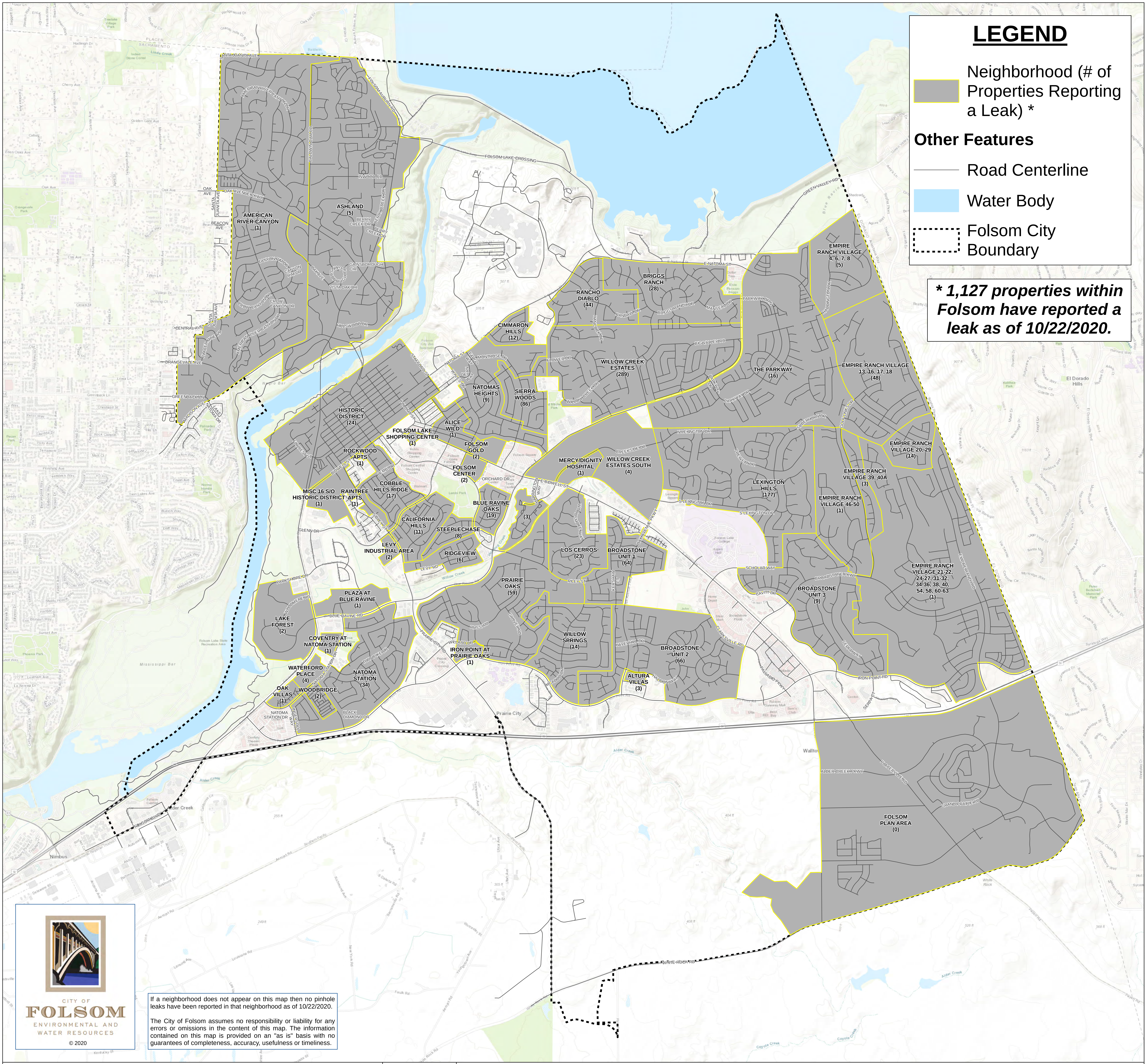

LEGEND

▨ Neighborhood (# of Properties Reporting a Leak) *

Other Features

Road Centerline

Water Body

Folsom City Boundary

**** 1,127 properties within Folsom have reported a leak as of 10/22/2020.***

If a neighborhood does not appear on this map then no pinhole leaks have been reported in that neighborhood as of 10/22/2020.

The City of Folsom assumes no responsibility or liability for any errors or omissions in the content of this map. The information contained on this map is provided on an "as is" basis with no guarantees of completeness, accuracy, usefulness or timeliness.

CITY OF
FOLSOM
ENVIRONMENTAL AND
WATER RESOURCES

0 2,500 5,000 10,000
Feet
1 inch = 1,250 feet

N

City of Folsom : Pinhole Leak Locations
(As of 10/22/2020)

Path to PDF Export- R:\Utilities\Misc. Utilities\Water Quality\Data\COF_Pinhole_Leaks_WebMap_36x36_20201023.pdf

Date: 10/23/2020 Page Size: 36" x 36" Drawn By: MBrewer Document Path: N:\2_GIS_STAFF\MBREWER\Water\Pinhole_Leaks\COF_Pinhole_Leaks_WebMap_36x36_20200923.mxd : 10/23/2020 4:36:21 PM

Appendix B. Lab Test Results

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Table 1 - Field Tests on Water Samples

HDR, Folsom
Folsom Copper Pinhole Investigation
Your #10254427, HDR Lab #20-0654LAB
30-Sep-20

Sample ID			Larkhall Circle	Rathbone Circle	Chalcedony Court
pH			8.4-8.0	9.8-8.1	8.4-8.0
Field Analyses		**Units**			
temperature		°C	28.4	24.3	28.4
dissolved oxygen	O_2	mg/L	8.11	7.84	8.11
dissolved carbon dioxide	CO_2	mg/L	ND	ND	ND
bicarbonate	HCO_3^{1-}	mg/L	7.3	24	7.3
total chlorine	Cl_2	mg/L	ND	0.5-1.0	1.0
free chlorine	Cl_2	mg/L	ND	ND	ND
total DIC*	C	mg/L	1.4	4.8	1.4
Ryznar Scaling Index			11	8.2	11

mg/L = milligrams per liter (parts per million) of water.
*DIC = dissolved inorganic carbon
ND = not detected
na = not analyzed

Table 1 - Laboratory Tests on Water Samples

HDR, Folsom
Folsom Copper Pinhole Investigation
Your #10254427, HDR Lab #20-0654LAB
1-Oct-20

Sample ID			Larkhall Circle	Rathbone Circle	Chalcedony Court
pH			7.6	7.6	7.5
Electrical Conductivity		mS/cm	0.07	0.07	0.06
Chemical Analyses					
Cations					
calcium	Ca^{2+}	mg/L	11	11	11
magnesium	Mg^{2+}	mg/L	2.7	2.7	2.7
sodium	Na^{1+}	mg/L	4.6	4.6	4.7
potassium	K^{1+}	mg/L	1.8	1.7	1.7
Anions					
carbonate	CO_3^{2-}	mg/L	ND	ND	ND
bicarbonate	HCO_3^{1-}	mg/L	47	50	44
fluoride	F^{1-}	mg/L	ND	ND	ND
chloride	Cl^{1-}	mg/L	4.2	4.1	4.0
sulfate	SO_4^{2-}	mg/L	1.4	1.4	1.4
phosphate	PO_4^{3-}	mg/L	ND	ND	ND
Other Tests					
ammonium	NH_4^{1+}	mg/L	ND	ND	ND
nitrate	NO_3^{1-}	mg/L	1.2	1.2	1.2
sulfide	S^{2-}	qual	na	na	na
Redox		mV	na	na	na

Electrical conductivity in millisiemens/cm.
mg/L = milligrams per liter (parts per million) of water.
Redox = oxidation-reduction potential in millivolts
ND = not detected
na = not analyzed