A

City of Tumwater Corrosion Control Study

PWS #89700Q

DOH Project Report

Tumwater, Washington

November 22, 2022

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Abbreviations

µg	microgram(s)
$CaCO_3$	calcium carbonate
CFR	Code of Federal Regulations
CSMR	Chloride-Sulfate Mass Ratio
DIC	Dissolved Inorganic Carbon
DOH	Washington State Department of Health
gpm	gallon(s) per minute
HDR	HDR Engineering, Inc.
L	liter(s)
LCR	Lead and Copper Rule
MDD	maximum day demand
mg	milligram(s)
ND	not detected
project report	Washington State Department of Health Project Report
SCADA	supervisory control and data acquisition
State	Washington State
TCE	trichlorethylene
WAC	Washington Administrative Code
WSP	Water System Plan
WTP	Water Treatment Plant
USEPA	U.S. Environmental Protection Agency

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Certification

City of Tumwater, Washington

PWS# 89700Q

Corrosion Control Study

This Project Report for the corrosion control study for the City of Tumwater's water system has been prepared under the direction of the following Registered Professional Engineer:

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11/22/2022

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1 Introduction and Purpose

The City of Tumwater (City) (Public Water System ID - 89700Q) retained HDR Engineering, Inc. to prepare an Engineering Report documenting that the City has optimal corrosion control per 40 CFR 141.81(b)(2). The main sources of lead and copper in drinking water stem from utility service lines and customer premise plumbing materials. These materials can include lead and copper pipe, lead goosenecks, lead/tin solder, and leaded brass materials used in faucets and fittings.

Water quality can affect the rate of corrosion of lead and copper materials, the formation and characteristics of scales that form on these materials, and ultimately, the release of metals into drinking water. Understanding the water quality conditions that impact the release of lead and copper in drinking water provides a foundation for establishing an optimal corrosion control treatment.

This report summarizes the City's water quality data and findings.

1.1 Prior Studies

The last known corrosion control study for the City was prepared three decades ago. This study, City of Tumwater Corrosion Control Study: Final Report (Norton Corrosion Limited, 1994), indicates it was prepared to comply with the then newly promulgated Lead and Copper Rule (LCR). However, the review focused on water storage reservoirs, the wells, sewage lift stations, fuel storage tanks, and soil samples. As such, the report devoted lengthy recommendations to repairing exterior water tank coatings, adding galvanic cathodic protection to submerged well piping and underground fuel storage tanks, and adding liners over exposed concrete within sewage lift stations.

The report did indicate that four homes had water quality samples taken and found to have copper concentrations greater than the 1.3 mg/L action level. However, there is no indication if the samples were stagnant samples or flowing water samples. In addition, three of the home samples were obtained at interior locations other than the kitchen tap.

A test was performed to raise the water pH using lime and soda ash. The control water pH was 6.8 and raised to as high as 11.6, though the test methodology is not described. The report indicated that raising the water pH reduced water corrosion, and that using lime was preferable to soda ash. The basis of this evaluation was based on open-circuit potentials (in units of millivolts) and induced corrosion currents (in units of microamps). No water chemistry results were provided.

Overall, the methodology and measurements of the 1994 report are those commonly used to study soil/pipe interface impacts on metal corrosion and not part of accepted LCR corrosion control studies today. As such, this prior document is not relied upon for the remainder of this report.

2 Water System Background

The City is located in Thurston County at the southern end of Puget Sound. In general, the City supplies drinking water to customers within the City's incorporated limits and the surrounding areas within the City's urban growth area. The City's existing service area serves a population of over 28,000, which is primarily composed of residential services. Figure 1 shows the City's historical service connection distribution by customer type from 2007 through 2016 (the last year of data in the City's 2020 Water System Plan). The City has a total of 12,641 service connections per the City's current Water Facilities Inventory (last updated March 14, 2022 per Washington Department of Health [DOH] Sentry database).

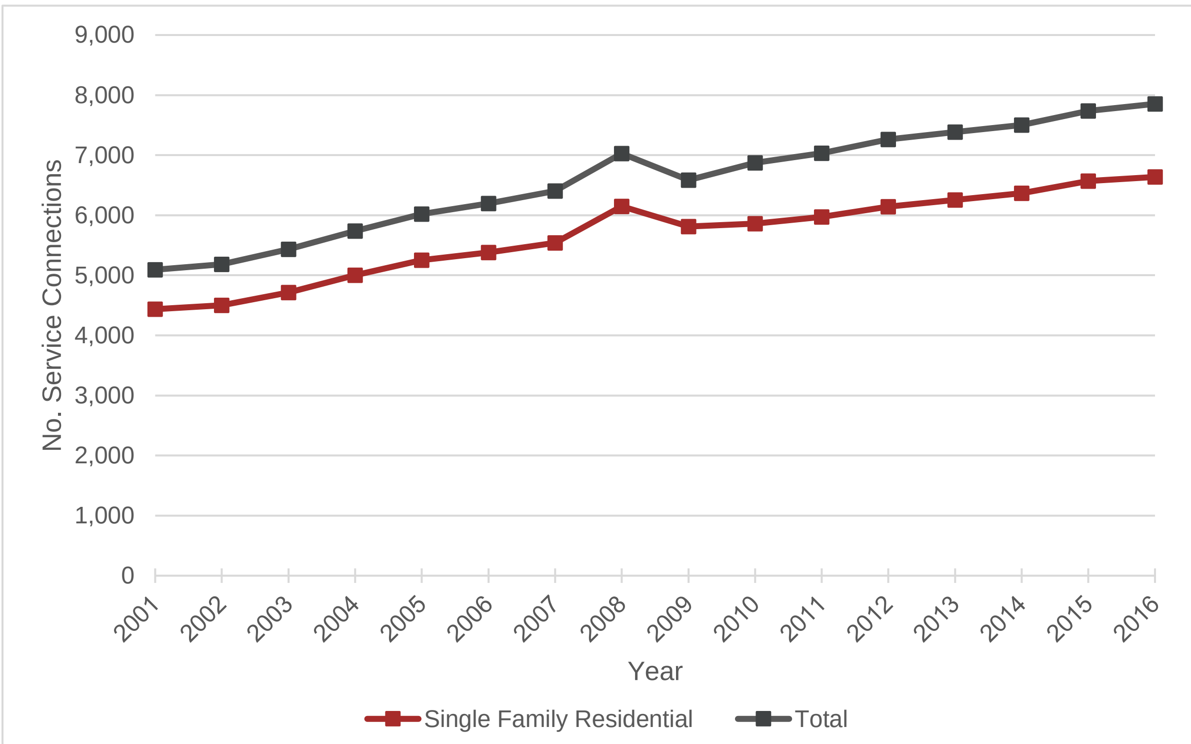


Figure 1. Historical Service Connections Distribution by Customer Type

The City observed a large growth in its housing stock since the late 1990s, or after the time lead/tin solder was banned for plumbing. The City has historically used galvanized iron or copper services. Additionally, there has been no history of installing or encountering either lead service lines or lead goosenecks based on discussions with the City's staff. Due to these factors, it is expected that few, if any, pure lead metals are in place currently within the City's service area. The principal sources of any lead in drinking water would be from leaded brass fixtures, valves, meters, and other appurtenances.

Copper is the predominant customer premise material in the City's service area. Pure copper usage extends from the service lines into building plumbing while mixed copper alloys are present in various brass and bronze appurtenances.

The City continues to grow, with new customers being added to the system each year. The projected service populations are listed in Table 1.

Table 1. Service Population Projections

Year	2017	2020	2025	2030	2035	2040	Average Annual Growth Rate
Service Population	28,443	32,555	37,057	41,319	43,904	47,159	2.3%

(Source: 2020 Comprehensive WSP Update)

2.1 Water Supply Overview

The City's existing water supply is three active wellfields and one emergency well. These supplies are summarized in Table 2, with greater description following afterwards.

Table 2. Water Supply Summary

Water Supply	Pumping Capacity	Treatment Processes	Discharge Location
Palermo Wellfield (Well Nos. 3, 4, 6, 8, 16, 18)	Rated: 2,190 gpm Current: 1,914 gpm Limited [a]: 1,520 gpm	Aeration, Chlorination	350 Pressure Zone
Bush Wellfield (Well Nos. 12, 14)	Rated: 3,025 gpm Current: 2,938 gpm	Aeration, Chlorination	350 Pressure Zone
Airport Wellfield (Well Nos. 9, 10, 11, 15)	Rated: 1,530 gpm Current: 1,540 gpm	Chlorination Only	350 Pressure Zone
Emergency Standby Well No. 24 [b]	Rated: 500 gpm Current: N/A	Chlorination Only	350 Pressure Zone

(Source: 2021 Comprehensive WSP Update, Table 1.2)
[a] Palermo Wellfield capacity is limited/restricted to less than the rated capacity to manage groundwater levels.
[b] In August 2019, Well 24 was taken offline and disconnected from the water system.

Figure 2 shows the City's water system facilities while Figure 3 presents a schematic of how the City's supplies are tied together, and each well's capacity. The City largely relies on the Palermo and Bush Wellfields to supply the majority of its demand. The Airport Wellfield is used less than the other two wellfields. The Airport Wells are typically used seasonally during the summer to meet higher system demands. The wellfields and wells discharge into the 350 Zone at different locations and there is no water system mixing unless different waters reach the 350 Reservoir, at which time a blended water leaves the reservoir outlet. As such, customers are typically supplied alternating water qualities based on what wells are in use at the time.

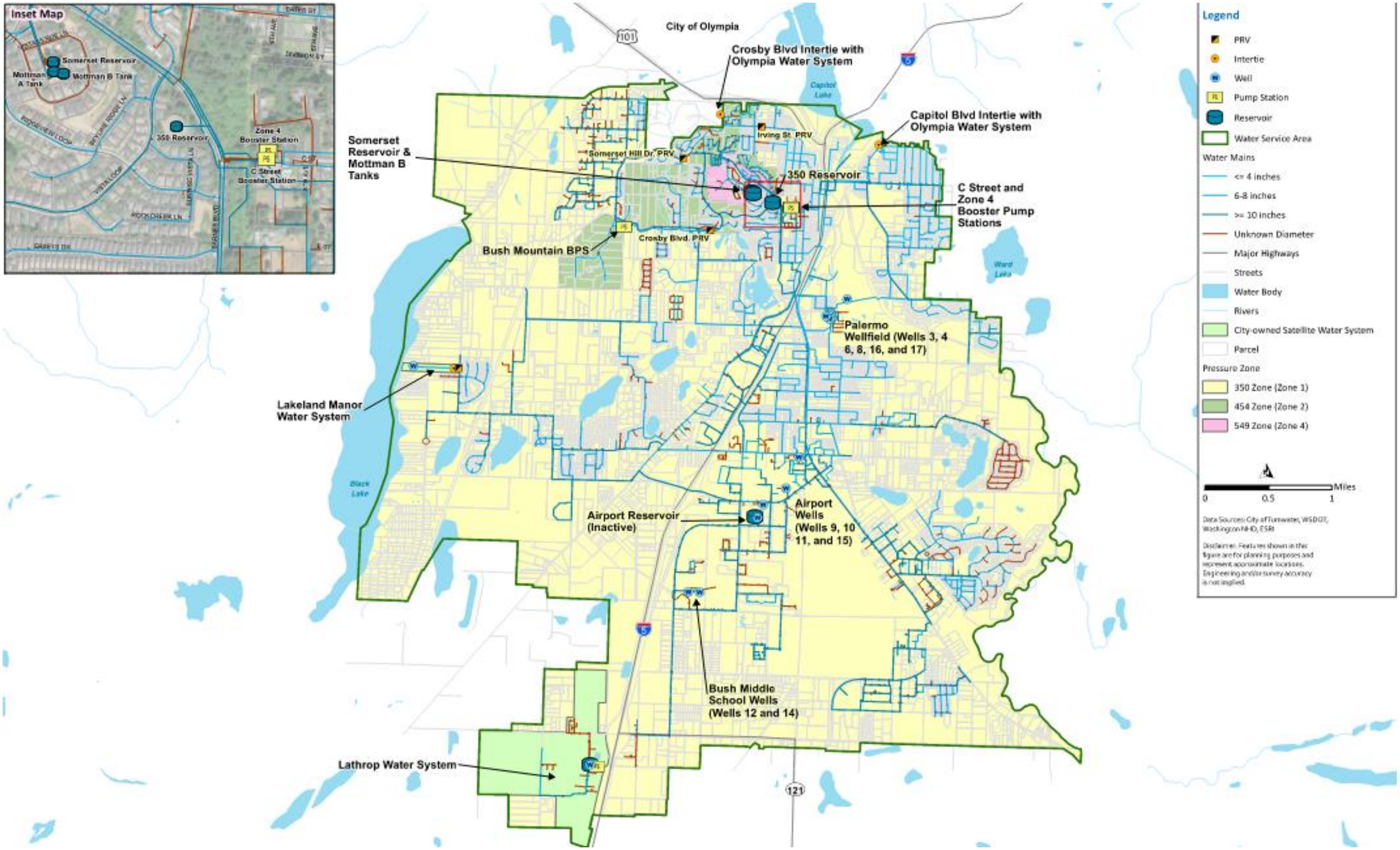


Figure 2. Water System
(Source: 2021 Water System Plan Update, Figure 1.4)

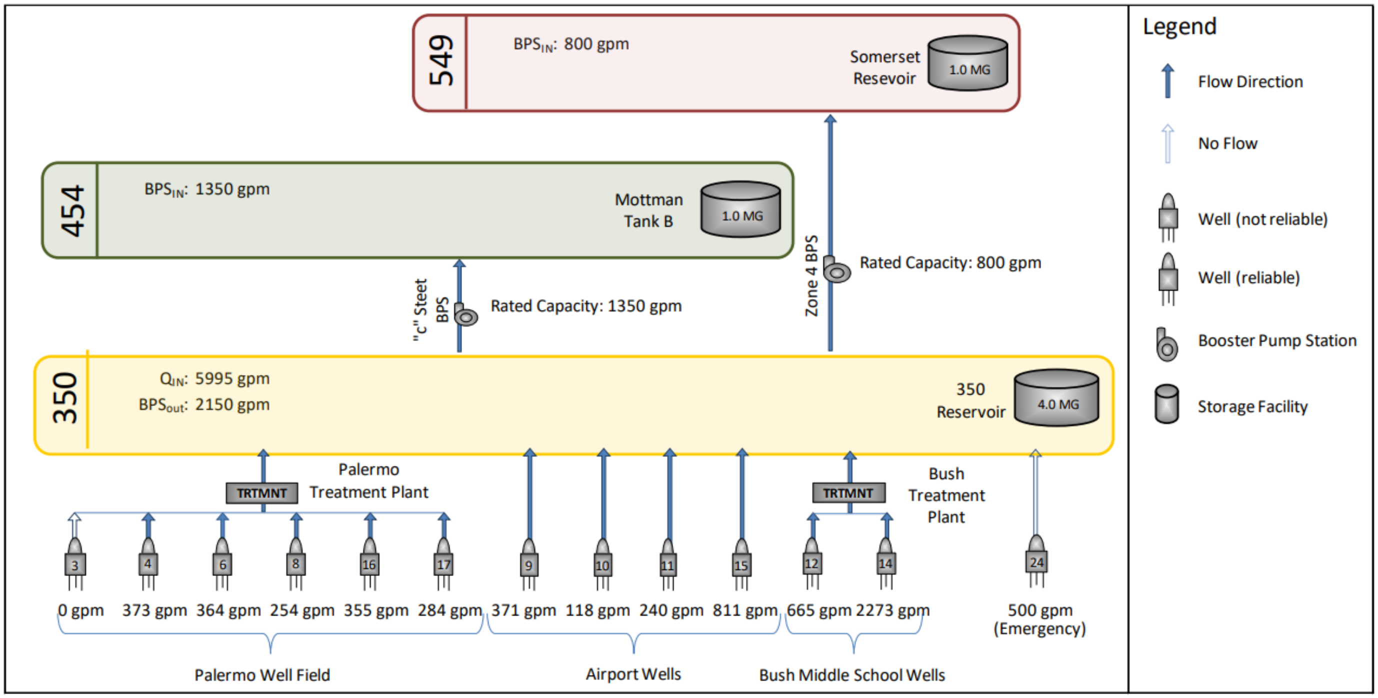


Figure 3. Existing Supply, Pumping, and Storage Configuration
(Source: 2021 Comprehensive WSP Update, Figure 5.1)

2.1.1 Palermo Wellfield and Palermo Treatment Plant

The Palermo Wellfield consists of six wells: Wells Nos. 3, 4, 6, 8, 16 and 17. Well 3 is currently not in use due to interference with the other Palermo wells. The groundwater from these wells discharge into the Palermo Water Treatment Plant (WTP), which is equipped with two packed aeration towers to remove trichlorethylene (TCE). Through this process, aeration also removes dissolved carbon dioxide in the water and raises the pH to 7.8 to 8.0. Following aeration, sodium hypochlorite is added to impart a chlorine residual and to inhibit biological growth within the towers. The Palermo WTP became operational in 1999.

2.1.2 Bush Wellfield and Bush Treatment Plant

The Bush Wellfield consists of Well Nos. 12 and 14. These two wells have low pH groundwater, similar to the wells in the Palermo wellfield, but no VOCs. The water is first passed through a single packed aeration tower (installed in 2000) to raise the water pH and then is chlorinated using sodium hypochlorite prior to pumping to the 350 pressure zone.

2.1.3 Airport Wells

There are four wells by the Olympia Regional Airport. Well Nos. 9 and 10 discharge into a common entry point into the distribution system while Well Nos. 11 and 15 have their own entry points to the distribution system. Unlike the Palermo and Bush Wellfields, the Airport Wells lack aeration facilities and the groundwater is only chlorinated.

3 Water Quality Parameters Impacting Corrosion

Corrosion in utility water systems and customer premise plumbing is defined as the electrochemical interaction between a metal surface, such as a pipe wall or solder, and water. During this interaction, metal ions are released from the pipe and transferred to the water. The extent of this interaction in terms of magnitude and speed of release is governed by various water quality parameters described in the following sections.

3.1.1 Water pH

Water pH exerts an effect on the solubility, reaction rates, and the surface chemistry of all corroding metals. Low pH levels potentially increase the solubility of copper and lead from premise plumbing and fixtures, iron from old unlined iron/steel mains, and galvanized iron services. At lower pH values, typically below 7, uniform corrosion of cold water piping dramatically increases. At higher pH values, there is a lower tendency for metal surfaces in contact with drinking water to dissolve and enter the water. In addition, pH stability is important to developing and maintaining protective metals scales in piping. Intermittent shifts between lower pH water and a higher pH water can be as detrimental to corrosion control as constantly maintaining a lower pH water throughout a distribution system.

pH is also a critical factor defining the carbonate balance because it impacts buffer capacity and dissolved inorganic carbon (DIC) concentrations. This water quality parameter is one of the predominant factors in controlling corrosion rates.

Maintaining a consistent pH throughout the distribution system is critical to minimizing lead and copper levels at the tap, even if other corrosion protection methods are employed. Fluctuations in pH can exert a similar, or sometimes larger, effect on metal corrosion and release than under continuous exposure to low pH. Distribution system pH for Western Washington utilities is typically maintained between 7.5 and 8.3.

3.1.2 Alkalinity, DIC, and Buffering Intensity

Alkalinity, DIC, and buffering intensity are three inter-related water quality parameters that significantly govern the extent of corrosion control in water systems. Alkalinity is a commonly analyzed water quality parameter that provides an indirect measure of a given water’s ability to resist changes in pH. Waters with high alkalinities tend to have higher buffering capacities than waters with lower alkalinities, allowing for better control and stable water pH throughout a distribution system and into customer premise plumbing systems.

DIC is the calculated sum of all of the carbonate species and is a factor for controlling corrosion. Direct analysis of DIC is not typically conducted by water quality laboratories due to expense. Instead, most water quality professionals estimate DIC by comparing pH, alkalinity, and water temperature data with published graphs produced by the U.S. Environmental Protection Agency (USEPA). DIC is primarily used as an indicator of lead corrosion as a higher concentration indicates the potential formation of strong, insoluble lead carbonate scales. DIC is also used as an indicator of potential copper corrosion.

Buffer intensity is the calculated resistance to changes in pH in water and is a function of pH and DIC. For water with a pH between 7.0 and 9.0, buffer intensity will increase as the water alkalinity increases. While buffer intensity is the most precise definition of a water's ability to resist pH changes, this term is rarely used as it involves a second mathematical calculation (the first being to calculate DIC) that requires specialized computer programs. This term is used in scientific articles on corrosion control; most industry corrosion studies use pH/alkalinity (two directly measured parameters) or pH/alkalinity/DIC (two measured parameters and one simple calculation).

3.1.3 Total Dissolved Solids (TDS) and Conductivity

TDS can have an impact on corrosion. High TDS concentrations, such as greater than 500 milligrams per liter (mg/L) TDS, increase the conductivity of water, which in turn provides an electrochemical driving force to pull metal ions from the pipe/plumbing surface and into the water. Conversely, very low TDS (less than 20 mg/L TDS) is also highly corrosive to metals as a different electrochemical force dissolves metals.

3.1.4 Temperature

Temperature plays a role in corrosion in that it impacts many parameters critical to corrosion including dissolved oxygen levels and biological activity. In general, colder temperatures result in less metal corrosion.

3.1.5 Oxidation-Reduction Potential (ORP), Dissolved Oxygen, and Chlorine

These parameters are various measures of water's capability to oxidize metals. ORP depends on a number of water quality parameters but is primarily driven by the concentrations of disinfectant (chlorine) and dissolved oxygen in the water. Low measures of any of these three parameters are often an indicator that copper, iron, and lead release could be occurring within premise plumbing.

3.1.6 Chloride and Sulfate

These two anions are key parameters in the calculation of the Chloride-Sulfate Mass Ratio (CSMR). CSMR has been identified in several published water quality papers as the key parameter to explain high lead corrosion rates when pH/alkalinity/DIC values would otherwise indicate optimized corrosion control treatment. In addition, high chloride concentrations (greater than 100 mg/L) alone have been found to cause increased copper corrosion rates from plumbing.

3.1.7 Microbial activity

Corrosion can also be caused by microbial activity in the water. Microbes can regrow in waters that are warm, absent of chlorine, and in the presence of food. Such food can be organic carbon, iron (for iron bacteria), and/or sulfur (for sulfur bacteria). Review of the City's data does not indicate any strong tendencies for microbial growth due to the maintenance of free chlorine residuals throughout the distribution system, the generally colder water temperatures, and the lack of coliform detections in routine monitoring.

However, this situation could occur in stagnant customer premise plumbing, such as an unused but heated guest restroom.

4 Water Quality Data

The following sections describe the historical corrosion-related treated and distribution system water quality data collected by the City, along with results of quarterly sampling conducted by the City starting in 2021.

4.1 Treated Water pH SCADA data

The City monitors pH through a Supervisory Control and Data Acquisition (SCADA) system at the Bush WTP and the Airport Wells. pH is not monitored by SCADA at the Palermo WTP.

Figure 4 shows the pH SCADA data for the Bush WTP starting on January 1, 2019. The City has recorded Bush WTP pH data since 2013 but data prior to 2019 is inaccurate due to infrequent instrumentation calibration procedures. For example, some results show extended periods of pH 2 water along with a spike in water pH up to 14. If accurate, such conditions would have generated considerable human health impacts, significant impacts to premise plumbing, negative damage to dental and healthcare equipment, hot water boilers, and household and commercial/industrial appliances. No such issues occurred. As such, this is not presented nor used in this analysis. The City indicates that procedures were updated in 2019 and the instruments are checked and calibrated on a more frequent basis now.

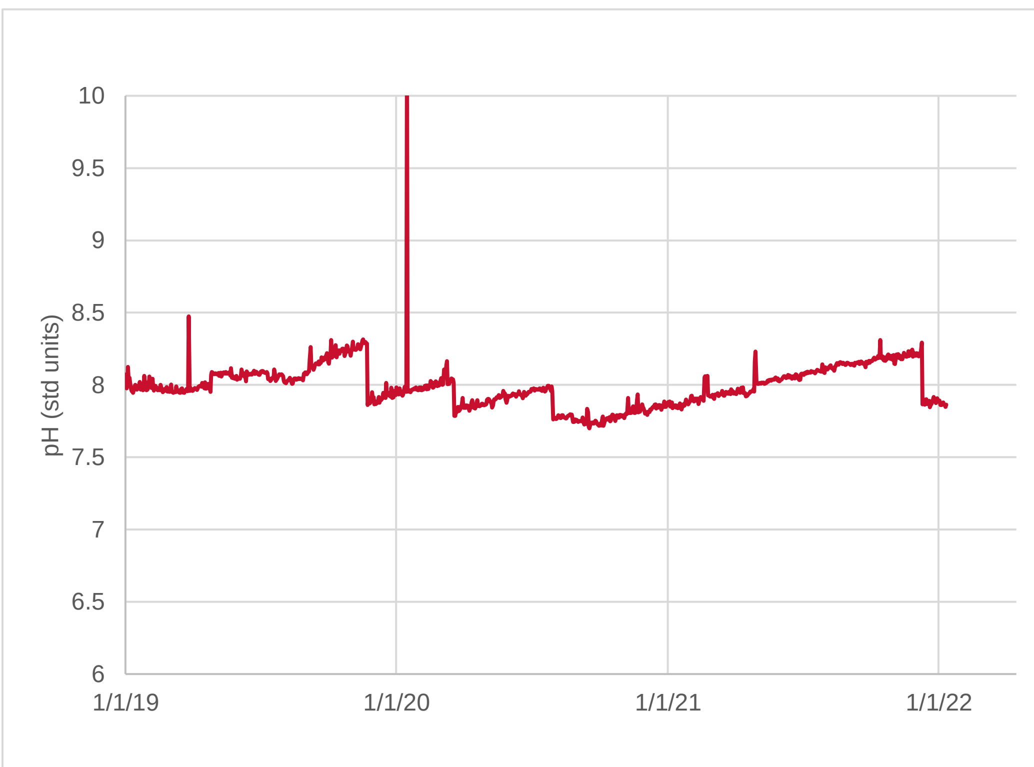


Figure 4. Bush Clearwell SCADA Data – pH (January 2019 to January 2022)

The SCADA-recorded online water pH data for the various Airport Wells is shown in Figure 5. As with the Bush WTP, the historical pH monitoring shows considerable variability atypical to Western Washington groundwaters. pH levels typically range above 7.0 but can be as high as 9.0 for several months or over 10.0 on a daily basis. Communications with City staff indicate that much of the pH changes are likely due to instrument drift and lack of calibration when the wells are offline during the winter. The City indicates the groundwater pH is relatively stable at 6.8 to 7.0.

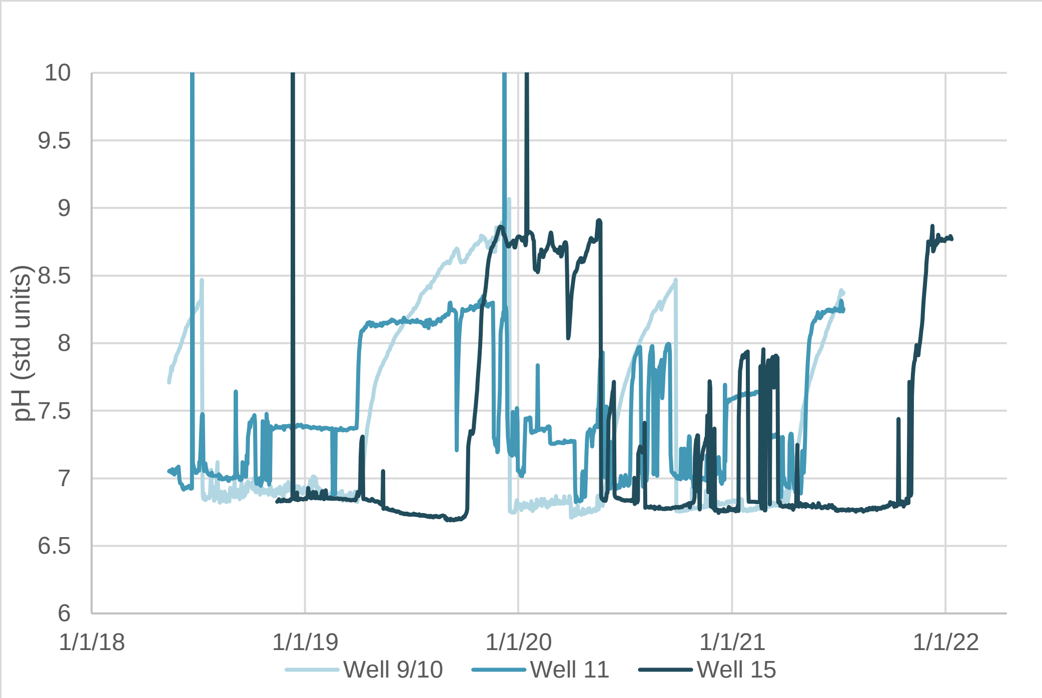


Figure 5. Airport Wells SCADA Data – pH (April 2018 to January 2022)

4.2 Additional Monitoring

The DOH directed the City to conduct additional water quality monitoring as part of the corrosion control investigation. In the request from August 19, 2019, the DOH required the following parameters be measured quarterly at each entry point to the distribution system and a minimum of ten locations throughout the distribution system:

- pH
- Alkalinity
- Calcium
- Conductivity
- Water temperature

Sampling was started in July 2021 and will conclude in July 2022. Sampling sites were selected from existing routine monitoring locations shown in Figure 6. Note that the site numbering was prepared for this report to replace use of personal home or business addresses.

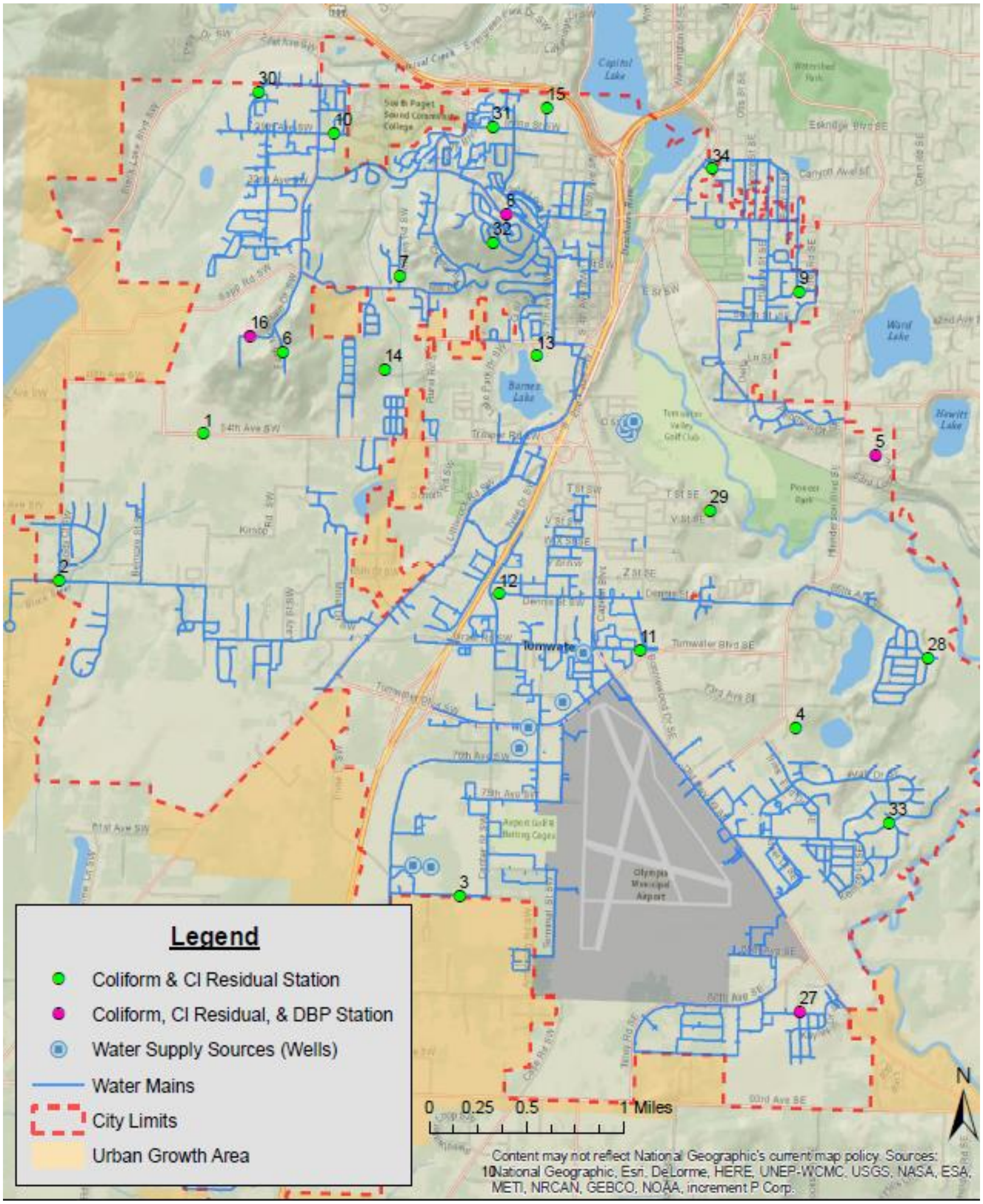


Figure 6. Sampling Stations in the City's Distribution System (Source: provided with sampling data)

4.2.1 Entry Point Water Quality Data

Samples collected at each entry point that inform the results of the corrosion control investigation are summarized in Table 3. The number of samples collected varies across each entry point since samples were only collected if the well was operating at the time of sampling. Therefore, the number of samples collected at the Airport Wells is lower than the number of samples collected at the Palermo and Bush WTPs. Water quality results are provided in Table 4, along with selected historic water quality data of parameters that have potential to impact corrosion.

In general, there is a distinct difference in the water quality between the Palermo and Bush Wellfields and the Airport Wells. The difference is due to the implementation of aeration at the two wellfields, whereas the individuals Airport Wells lack such treatment. Specifically, water from the Airport Wells have considerably lower pH and higher DIC and alkalinity than the Palermo and Bush waters as shown in Figure 7, Figure 9 and Figure 10. Figure 8 illustrates that temperatures are stable and typical of those of shallow western Washington aquifers, which are conducive to minimizing corrosion. As noted earlier, pH and DIC are key indicators of increased corrosion potential. As such, this increased potential occurs whenever one or more of the Airport Wells are operate and displaces the higher pH Palermo and Bush water from service area surrounding the Airport Wells. Since the Airport Wells are infrequently used, this displacement causes swings in water pH between ~7.0 and ~8.0, which can be detrimental to the formation and preservation of protective corrosion scales.

In addition, the higher alkalinities of the Airport Wells water than the other two waters means that the water is more buffered and resists pH changes. This fact is important if the water from the City's wells blend as the blended water will be considerably closer in pH to the Airport Wells, and therefore more corrosive, than either aerated Palermo or Bush water.

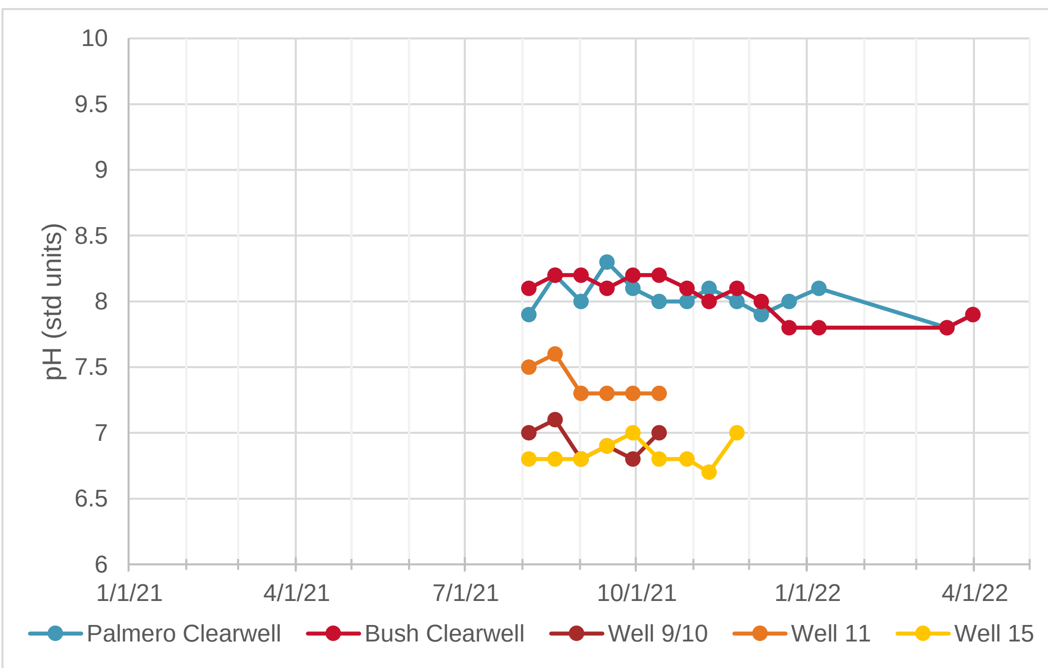


Figure 7. Measured pH, Distribution Entry Points When in Use (August 2021 to March 2022)

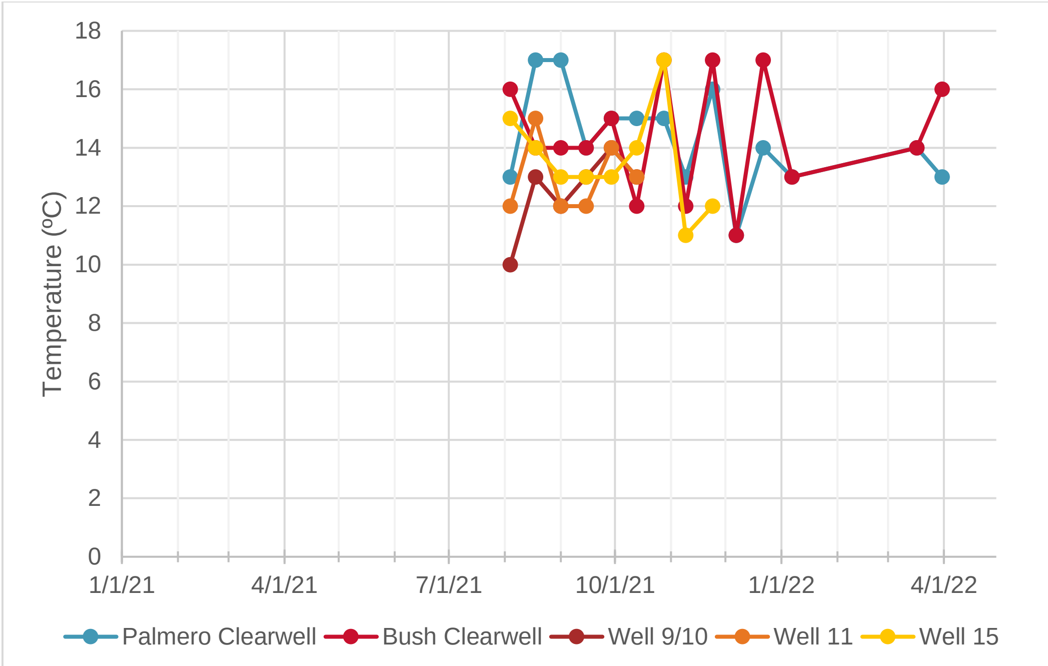


Figure 8. Measured Temperature, Distribution Entry Points When in Use (August 2021 to March 2022)

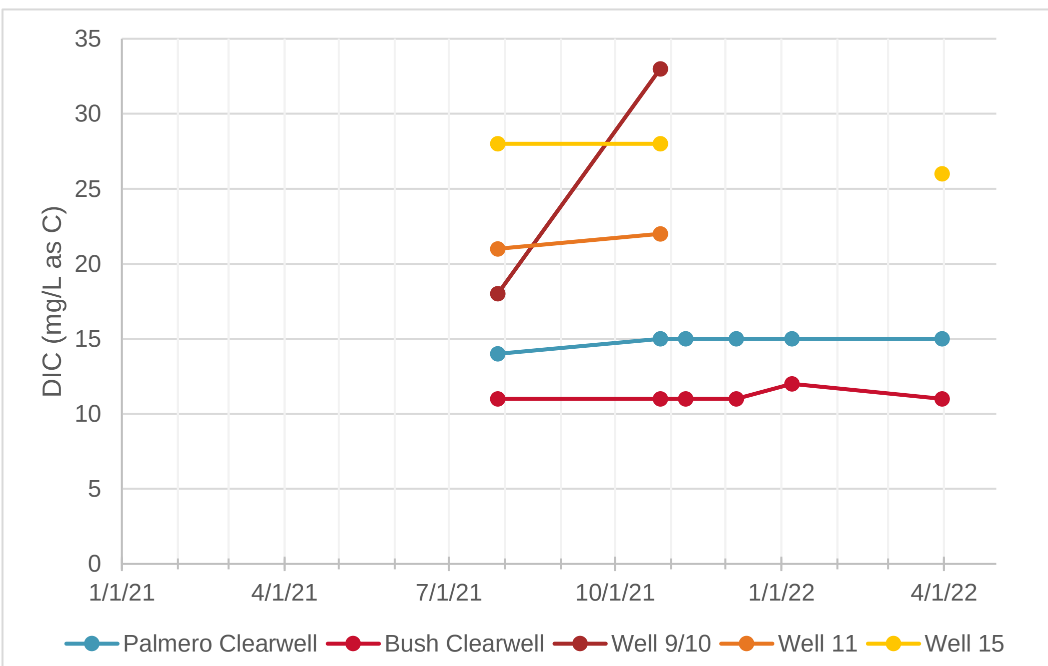


Figure 9. Calculated DIC, Distribution Entry Points When in Use (July 2021 to March 2022)

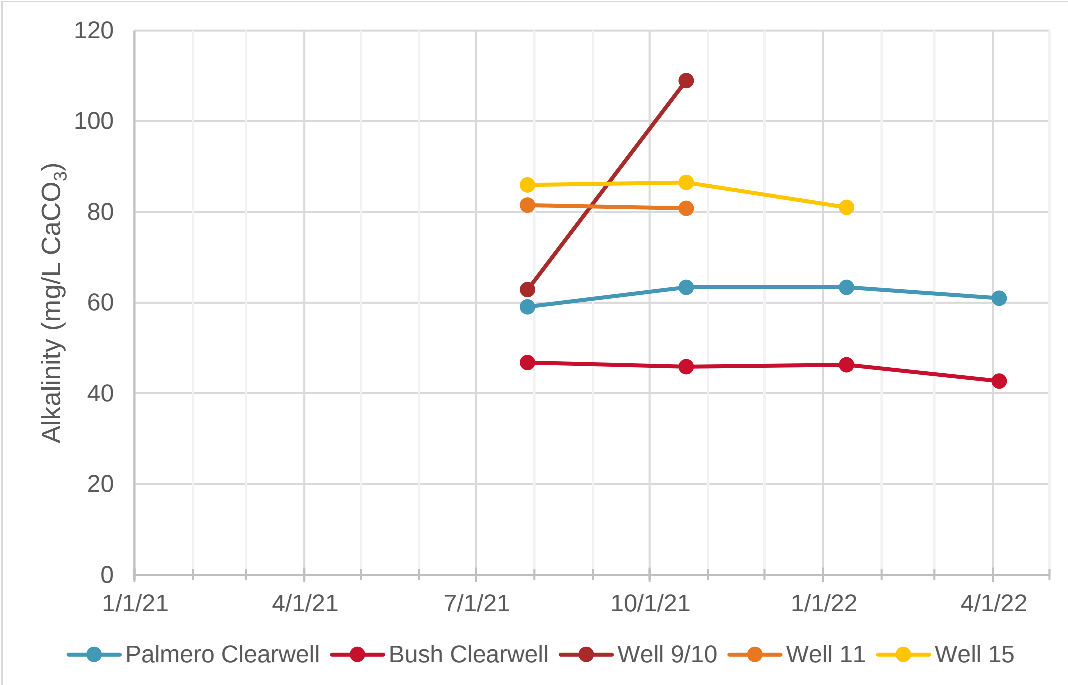


Figure 10. Measured Alkalinity, Distribution Entry Points When in Use (August 2021 to April 2022)

Table 3. Select Water Quality Parameters of the City's Water Supplies – Entry Point Number of Samples Collected

Parameter	Palermo Clearwell	Bush Clearwell	Wells 9/10	Well 11	Well 15
pH [a, b]	14	14	6	6	9
Temperature [a, b]	14	14	6	6	9
Alkalinity [b]	4	4	2	2	3
Calcium [b]	4	4	2	2	3
Conductivity [b]	4	4	2	2	3
Total Chlorine	1	1	1	1	1
Free Chlorine	1	1	1	1	1
Hardness [c]	1	1	1	1	1
Total Dissolved Solids [c]	1	1	1	1	1
Chloride [c]	1	1	1	1	1
Sulfate [c]	1	1	1	1	1
Iron [c]	1	1	1	1	1
Manganese [c]	3	1	1	1	1
DIC [d]	N/A	N/A	N/A	N/A	N/A

[a] Sampled biweekly.
[b] Sampled quarterly.
[c] Based on IOC sampling data.
[d] Dissolved Inorganic Carbon (DIC) calculated based on sample pH and alkalinity values.

Table 4. Select Water Quality Parameters of the City's Water Supplies – Entry Point Data

Parameter	Units	Limit [a]	Palermo Clearwell Average (Range)	Bush Clearwell Average (Range)	Wells 9/10 Average (Range)	Well 11 Average (Range)	Well 15 Average (Range)
pH	Std. Units	6.5 to 8.5	8.0 (7.8 to 8.3)	8.0 (7.8 to 8.2)	6.9 (6.8 to 7.1)	7.4 (7.3 to 7.6)	6.8 (6.7 to 7.0)
Temperature	ºC	-	14 (11 to 17)	14 (11 to 17)	13 (10 to 14)	13 (12 to 15)	14 (11 to 17)
Alkalinity	mg/L as $CaCO_3$	-	61.7 (59.1 to 63.4)	45.4 (42.7 to 46.8)	86.0 (62.9 to 109.0)	81.2 (80.8 to 81.5)	84.5 (81.0 to 86.5)
Calcium	mg/L as Ca	-	12.2 (9.7 to 13.5)	11.7 (10.8 to 12.8)	13.0 (12.5 to 13.5)	16.9 (15.7 to 18.0)	16.7 (16.2 to 17.6)
Conductivity	µS/cm	700	153 (144 to 159)	121 (113 to 128)	130 (125 to 136)	178 (168 to 188)	179 (173 to 187)
Total Chlorine	mg/L as Cl_2	-	0.52	0.45	0.37	0.50	0.59
Free Chlorine	mg/L as Cl_2	4.0	0.50	0.42	0.35	0.48	0.55
Hardness [b]	mg/L	-	57.6	41.7	54.7	69.7	82.3
Total Dissolved Solids [b]	mg/L	500	112	104	102	129	139
Chloride [b]	mg/L	250	5.3	4.4	3.7	4.8	4.1
Sulfate [b]	mg/L	250	5.2	4.2	3.9	3.2	4.2
Iron [b]	mg/L	0.3	Non-detect	Non-detect	Non-detect	Non-detect	Non-detect
Manganese [b]	mg/L	0.05	0.012 (0.011 to 0.013)	Non-detect	Non-detect	Non-detect	Non-detect
DIC [c]	mg/L as C	-	15 (14 to 15)	11 (11 to 12)	26 (18 to 33)	22 (21 to 22)	27 (26 to 28)

[a] Maximum contaminant levels per WAC 246-290-310.
[b] Based on IOC sampling data
[c] Dissolved Inorganic Carbon (DIC) calculated based on sample pH and alkalinity values.

4.2.2 Distribution Water Quality Data

As described previously, sampling is also being conducted at ten distribution system locations. A summary of distribution samples collected to date is presented in Table 6 and the number of samples at each location that inform this data is presented in Table 5. Water samples currently indicate an average pH of 7.7 with a range of 6.8 to 8.3. The majority of sampling locations have an average pH of 8.0, with the exception of sample sites WQ28 and WQ33, where the average pH was 7.0. WQ28 and WQ33 are less than a mile away from each other and are west of the Olympia Regional Airport.

Average alkalinity levels at the distribution sample sites range between 44 and 61 mg/L as $CaCO_3$. While most distribution samples have exhibited relatively consistent alkalinity during the sampling period, the alkalinity levels at WQ28 and WQ33 have decreased by nearly half since the beginning of sampling. This significant range in alkalinity for WQ28 and WQ33 is also apparent in the large range of DIC levels.

The samples have an average free chlorine residual of 0.36 mg/L as Cl_2, based off three to four samples taken at each location in August 2021. While the average chlorine levels are above the DOH's required disinfectant level of 0.2 mg/L, WQ26 had measurements below the required level. It is recommended that the City further investigate the chlorine levels at WQ26 since low levels may pose LCR compliance issues.

Table 5. Select Water Quality Parameters of the City's Water Supplies – Distribution System Data Number of Samples Collected

Parameter	WQ2	WQ3	WQ6	WQ8	WQ9	WQ10	WQ12	WQ26	WQ28	WQ33
pH [a, b]	15	18	15	16	15	16	15	15	14	15
Temperature [a, b]	15	18	15	16	15	16	15	15	14	15
Alkalinity [b]	4	4	4	4	4	4	4	3	4	4
Calcium [b]	4	4	4	4	4	4	4	3	4	4
Conductivity [b]	4	4	4	4	4	4	4	3	4	4
Total Chlorine	4	4	4	5	4	5	5	4	4	4
Free Chlorine	4	4	4	5	4	5	5	4	4	4
DIC [c]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[a] Sampled biweekly.

[b] Sampled quarterly.

[c] Dissolved Inorganic Carbon (DIC) calculated based on sample pH and alkalinity values.

Table 6. Select Water Quality Parameters of the City's Water Supplies – Distribution System Data

Parameter	Units	WQ2 Average (Range)	WQ3 Average (Range)	WQ6 Average (Range)	WQ8 Average (Range)	WQ9 Average (Range)	WQ10 Average (Range)	WQ12 Average (Range)	WQ26 Average (Range)	WQ28 Average (Range)	WQ33 Average (Range)
pH	Std. Units	7.9 (7.4 to 8.2)	8.0 (6.9 to 8.2)	8.0 (7.3 to 8.2)	8.0 (7.3 to 8.2)	8.0 (7.5 to 8.3)	8.0 (7.4 to 8.1)	8.0 (7.1 to 8.1)	8.0 (7.6 to 8.3)	7.0 (6.8 to 8.0)	7.0 (6.8 to 8.2)
Temperature	ºC	13 (7 to 18)	13 (11 to 18)	15 (7 to 21)	14 (7 to 19)	16 (9 to 24)	16 (8 to 23)	14 (11 to 17)	14 (9 to 19)	16 (9 to 21)	14 (9 to 18)
Alkalinity	mg/L as $CaCO_3$	44.7 (42.1 to 46.0)	45.3 (42.8 to v46.6)	54.3 (52.7 to 56.4)	55.1 (53.4 to 56.0)	61.1 (59.4 to 63.1)	53.0 (50.2 to 56.2)	46.3 (42.5 to 50.5)	44.2 (42.3 to 46.3)	54.1 (44.4 to 71.8)	52.9 (42.2 to 69.3)
Calcium	mg/L as Ca	12.2 (11.5 to 12.9)	12.4 (9.9 to 13.9)	12.6 (10.5 to 14.2)	13.5 (12.8 to 14.0)	13.6 (12.9 to 14.6)	13.1 (12.0 to 13.9)	12.4 (11.4 to 13.2)	12.3 (12.0 to 12.5)	13.0 (12.0 to 14.3)	13.6 (11.4 to 15.6)
Conductivity	mg/L as Cl_2	121 (115 to 126)	122 (115 to 128)	138 (128 to 148)	139 (129 to 145)	153 (144 to 162)	137 (134 to 140)	122 (115 to 128)	120 (112 to 127)	134 (124 to 146)	133 (120 to 149)
Total Chlorine	mg/L as Cl_2	0.44 (0.36 to 0.50)	0.40 (0.38 to 0.40)	0.43 (0.41 to 0.45)	0.47 (0.45 to 0.53)	0.38 (0.36 to 0.39)	0.36 (0.33 to 0.38)	0.42 (0.36 to 0.46)	0.25 (0.21 to 0.28)	0.45 (0.41 to 0.49)	0.47 (0.46 to 0.48)
Free Chlorine	mg/L	0.36 (0.34 to 0.37)	0.36 (0.35 to 0.37)	0.40 (0.38 to 0.43)	0.44 (0.40 to 0.48)	0.34 (0.33 to 0.36)	0.30 (0.23 to 0.36)	0.37 (0.29 to 0.40)	0.21 (0.19 to 0.24)	0.42 (0.40 to 0.43)	0.43 (0.42 to 0.43)
DIC [a]	mg/L as C	11 (10 to 11)	11. (11 to 12)	14 (13 to 14)	14 (13 to 15)	15 (15 to 15)	13 (13 to 15)	12 (11 to 14)	11 (10 to 12)	14 (12 to 22)	14 (11 to 22)

[a] Dissolved Inorganic Carbon (DIC) calculated based on sample pH and alkalinity values.

4.3 Lead and Copper Rule Compliance

The EPA developed the LCR to reduce lead and copper concentrations in drinking water that can occur when corrosive source water, typically water with a pH of less than 7.5, causes lead and copper to leach from utility services and residential plumbing. Per Title 40 of the Code of Federal Regulations (CFR) Part 141, last amended June 16, 2021, the LCR established an action level (AL) of 15 µg/L for lead and 1.3 mg/L for copper, and a lead trigger level of 10 µg/L. The action or trigger levels are triggered if the concentration of lead or copper exceeds the respective limit at the 90th percentile (P90) of their respective samples.

Table 7 summarizes the LCR results the City has collected to date. The following sections provide additional lead and copper sample data.

Table 7. Lead and Copper LCR Results

Sampling Year	No. Samples	Lead (µg/L) Action Level: 15 µg/L Trigger Level: 10 µg/L	Copper (mg/L) Action Level: 1.30 mg/L
		90th Percentile	90th Percentile
1992	60	4	0.150
2000	120	4	0.150
2004	38	**10**	0.261
2007	46	**11**	0.425
2010	31	9	0.347
2013	38	3	0.309
2015	10	2	0.309
2016	45	3	0.359
2019	30	6	0.217
2022	30	9	0.166

Note: Values that meet or exceed the lead trigger level are shown in red.

The latest compliance sampling event was in August 2022. This included sampling 30 locations for lead and copper. This effort also included investigative sampling at 96 locations. Of the 30 compliance samples, lead concentrations at 13 of the sites were non-detect, 14 were below the 10 µg/L trigger level, zero were above the trigger level but less than the 15 µg/L action level, and three were greater than the action level.

Of the 96 investigative samples, lead concentrations at 75 of the sites were non-detect, 18 were below the 10 µg/L trigger level, one was above the trigger level but less than the 15 µg/L action level, and one was greater than the action level. Follow-up sampling was conducted at the four sites with lead concentrations above the action level. Results are summarized in Table 8.

Table 8. 2022 Follow-Up Sampling Results

Site	August 2022 Sampling Lead (µg/L)	October 2022 Sampling Lead (µg/L)
Compliance		
A	57.9	3.3 (Upstairs), 22.4 (Downstairs)
B	26.6	1.3
C	24.9	2.4
Investigative		
D	28.5	ND

4.3.1 Lead Sampling

Figure 11 provides lead sampling results showing the percent occurrence of different lead levels. Sampled lead levels have generally been at or below the action or trigger levels in more than 90 percent of samples. However, the City's P90 lead levels met and exceeded 10 µg/L in 2004 and 2007. While these concentrations were acceptable per the LCR at the time, any future detections at these levels would trigger several additional corrosion control activities per the Lead and Copper Rule Revisions promulgated in Dec. 2021.

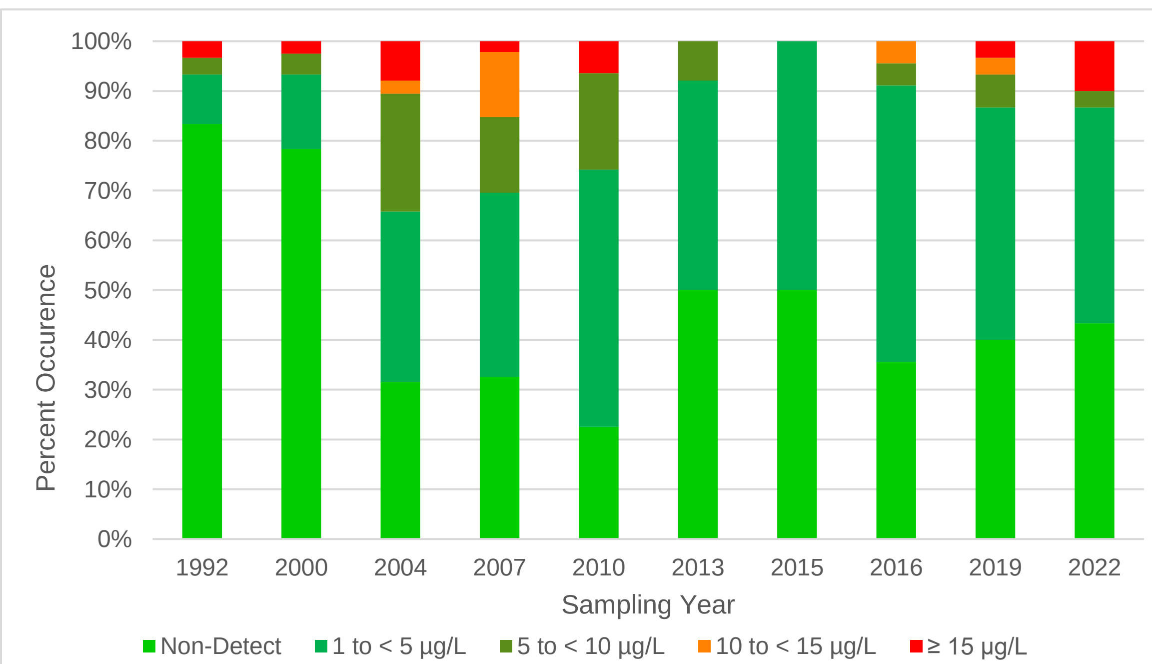


Figure 11. Lead Sampling Results
(Note: Palermo WTP started 1999, Bush WTP started 2000)

Further Analysis

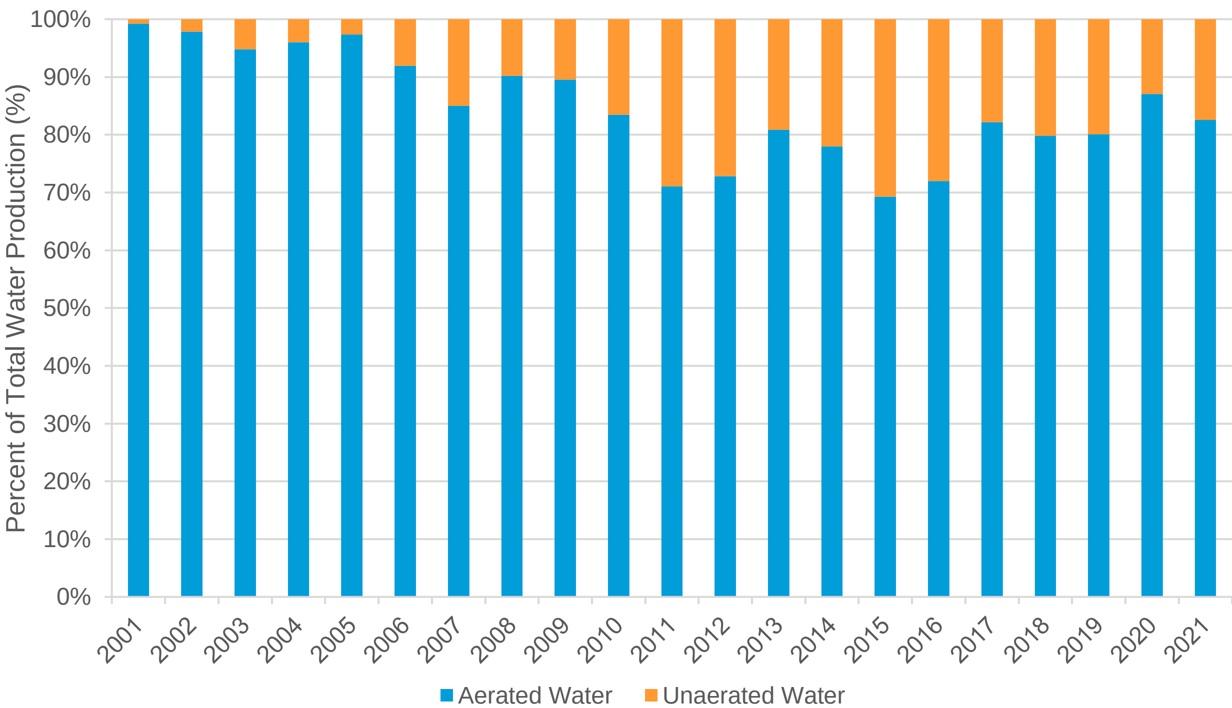
HDR reviewed annual well production data provided by the City since 2001 and lead sampling locations to investigate any trends that may result in the variation in lead concentrations over the years.

Water Production Analysis

Figure 12 presents the percent of water production that was aerated versus unaerated from 2001 through 2021 (i.e. pH adjusted versus not pH adjusted). The use of unaerated, lower pH water has increased over the years, with it accounting for at least 10 percent of the City's annual production since 2007 and accounting for 20 to 25 percent of its annual production for most years since 2011.

Figure 13 further breaks this out into the gallons of water produced from each water source. Bush Wellfield has been the largest producer over the years, accounting for 50 percent of water production for all years besides 2001, 2004, and 2007. Palermo Wellfield is the next largest producer, accounting for at least 20 percent of water production from 2001 to 2016. Production from the Palermo Wellfield decreased from 2009 to 2016, but has been increasing since 2017, accounting for over 25 percent of the annual water production in 2021. Use of the Airport Wells has increased over time, with them accounting for at least 10 percent of annual production since 2008.

Figure 14 presents similar data of water production for the month prior to the LCR sampling. As with the overall annual production trend, the analysis shows that increasing amounts of unaerated/lower pH water is present throughout the distribution system prior to sampling, which could negatively impact corrosion control results.



Notes:
• System-wide disinefection began late 2004 with a brief hiatus in 2006.
• Full-time disinfection using sodium hypochlorite has been in operation since 2007

Figure 12. 2001 to 2021 Aerated Water vs. Unaerated Water

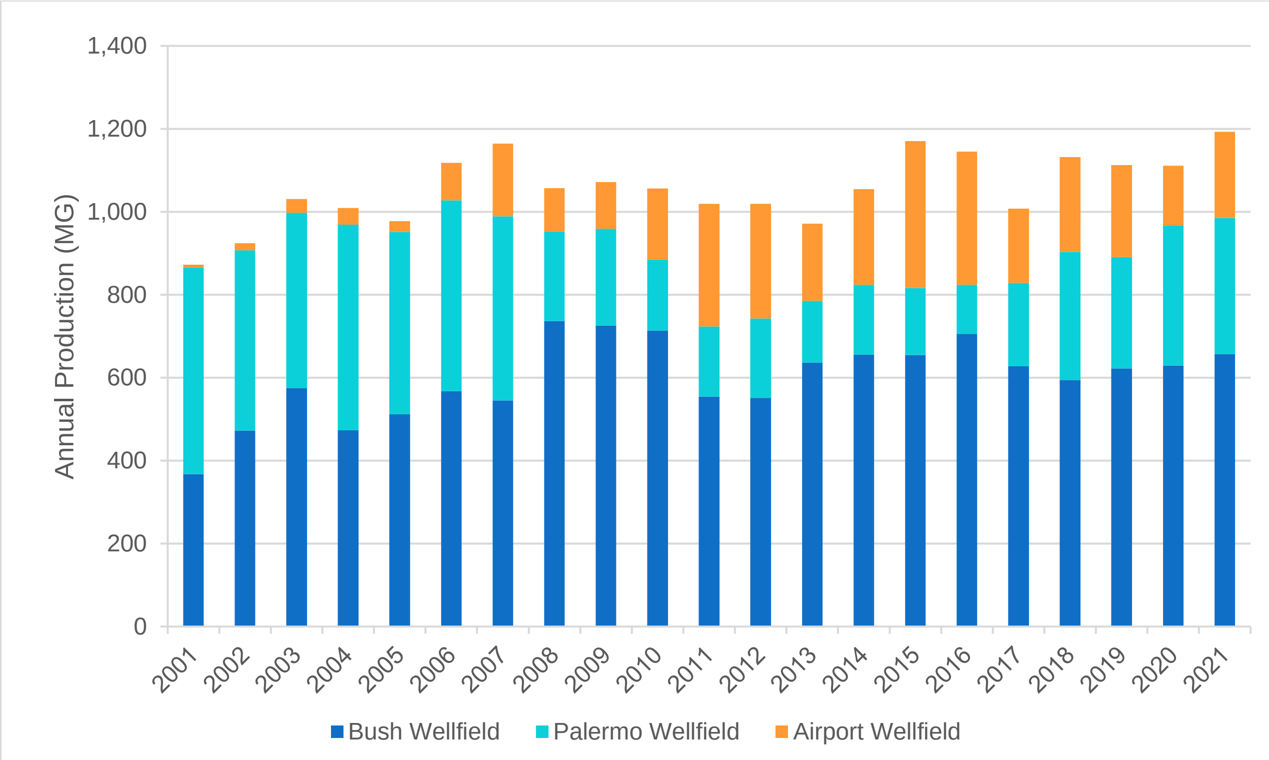


Figure 13. 2001 to 2021 Annual Well Production for Tumwater Water System in MG

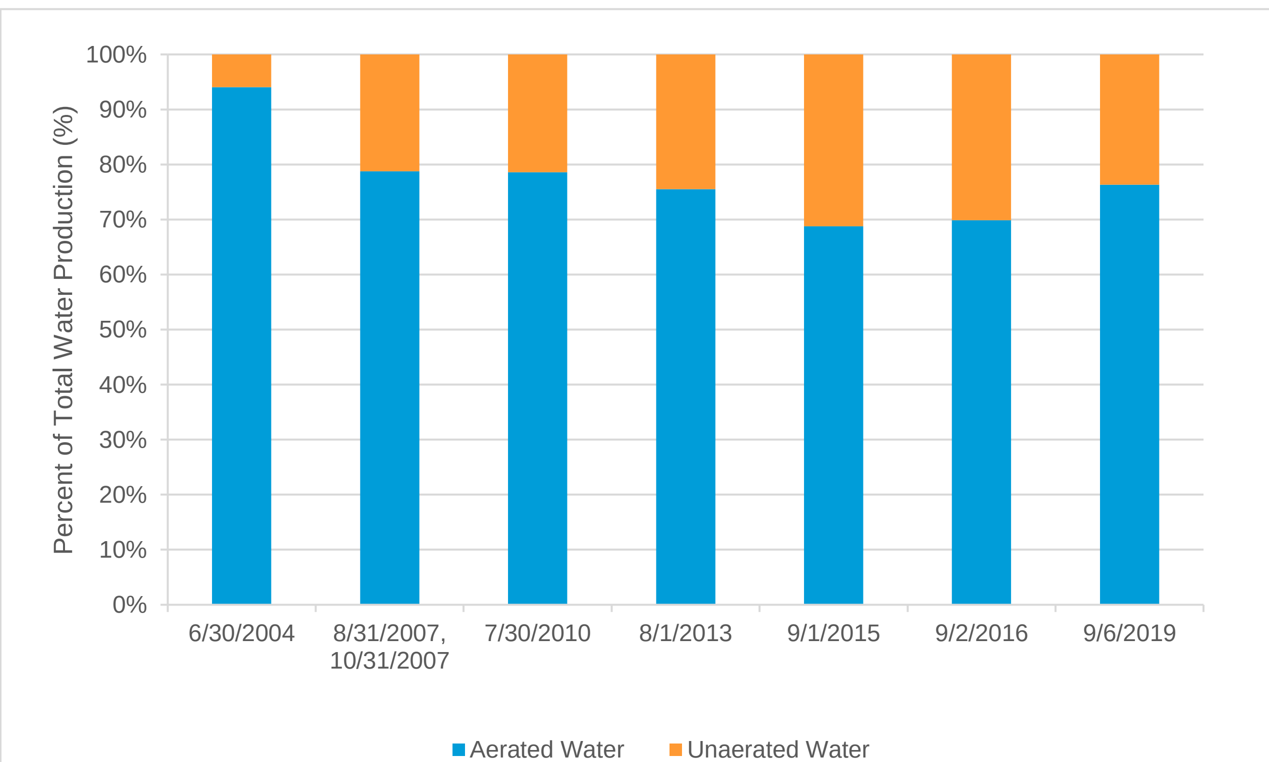


Figure 14. Aerated Water vs Unaerated Water Prior to LCR Sampling

Table 7 and Figure 11 indicate that the best year for LCR compliance (i.e., the year with the lowest overall lead results) was 2015, while Figure 12 shows the City's historical use of unaerated, more corrosive water was greatest that same year. In addition, Figure 14 shows that Airport Well usage was high during the month prior to the LCR sampling. There is no specific explanation for this apparent conflict but it must be noted that only ten LCR compliance samples were collected this year, far less than all other years. One hypothesis is that the limited sampling was conducted in areas that were receiving Palermo or Bush Wellfield water instead of waters from the Airport Wells.

Temporal Analysis

HDR reviewed lead sampling results from sites with four or more sampling events since system-wide disinfection was implemented in 2007. Figure 15 presents concentrations at seven sites that met these criteria. Note that several of the data points in the chart are on top of each other.

The analysis does not find a discernable pattern in detected lead concentrations. For example, Site 4 was found to have 110 µg/L lead in 2007 but 5 µg/L in 2010 and 2 µg/L in both 2013 and 2016. Conversely, Site 23 had < 4 µg/L lead in 2010, 2013, and 2019, but was found to have 14 µg/L in 2016.

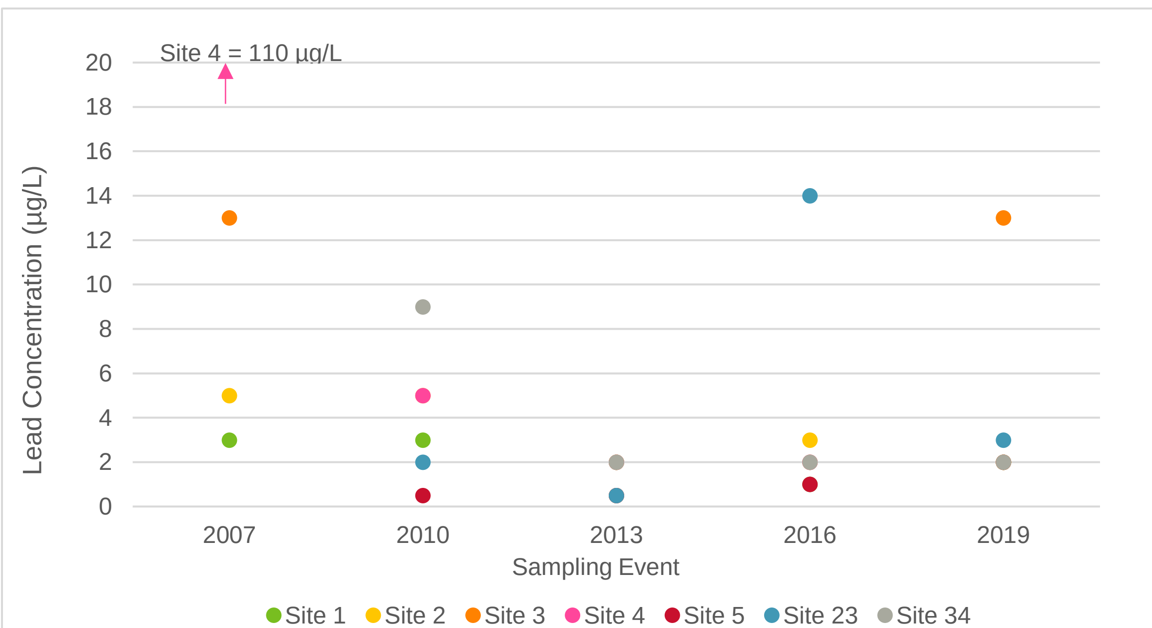


Figure 15. Temporal Analysis of Lead and Copper Sampling Events from 2007 through 2019

4.3.2 Copper Sampling

The City has routinely sampled for copper within its distribution system as required, and has largely stayed at or below 0.64 mg/L, and has never exceeded the action level of 1.3 mg/L. Figure 16 shows the results of the City's sampling over the past few decades.

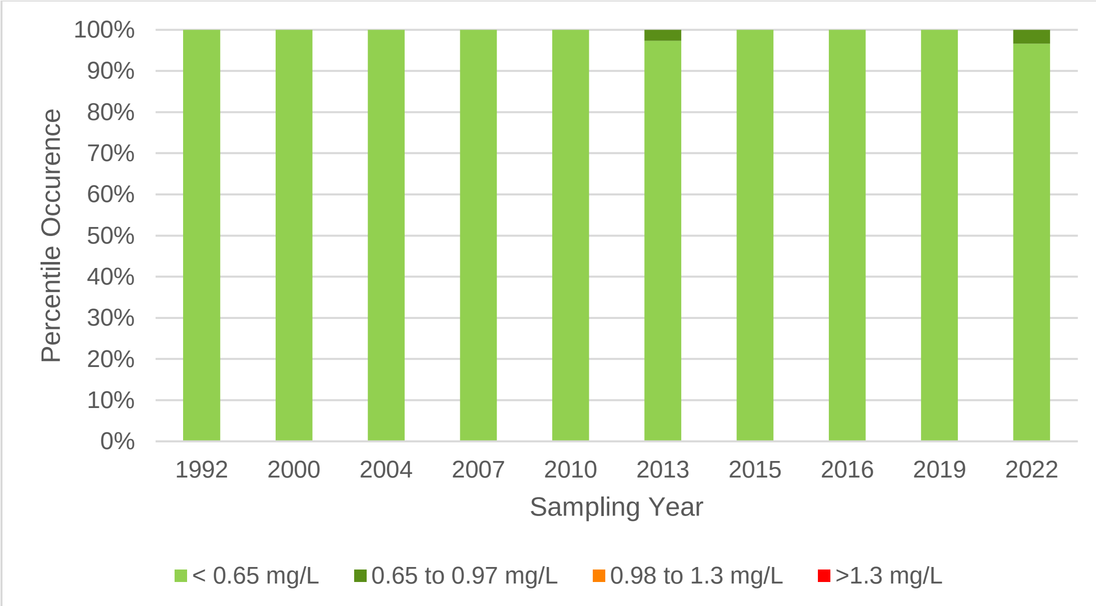


Figure 16. Copper Sampling Results
(Note: Palermo WTP starts 1999, Bush WTP starts 2000)

5 Treatment Implementation Alternatives

The aeration installed at the Palermo and Bush WTPs results in a higher pH and a more stable water quality that is conducive to reducing corrosion. Although the Airport Wells have a higher alkalinity, the low pH results in higher DIC values compared to the other water sources. Therefore, the water quality from the Airport Wells pose the greatest corrosion risk in the distribution system. There are several treatment options the City can implement at the Airport wells to match the water quality of the Palermo and Bush Wellfields to limit the water quality variability between the three wellfields and to reduce the potential of corrosion issues. HDR recommends implementing the addition of 25% caustic soda or aeration at the Airport Wells to raise the water pH if well usage remains high and future 90th percentile lead results exceed the 10 μg/L trigger level.

Due to the decentralized nature of the four Airport Wells, the City should consider if any treatment added should be decentralized (i.e. at individual wells), centralized to a single location, or a hybrid of the two. These scenarios are depicted in Figure 17 to Figure 19 .

Figure 17. Decentralized Treatment Piping

The decentralized treatment option (Figure 17) maintains the existing operation of the Airport Wells and includes treatment at each well site (Wells 9/10, Well 15, and Well 11).

Figure 18. Hybrid Treatment Piping

The hybrid treatment option (Figure 18) involves routing well water from Well 15 to Well 10 where the existing 8-inch line can be reused to bring water to the treatment site at Well 9. Well 11, given its distance away from the other wells, would have its own wellhead treatment system.

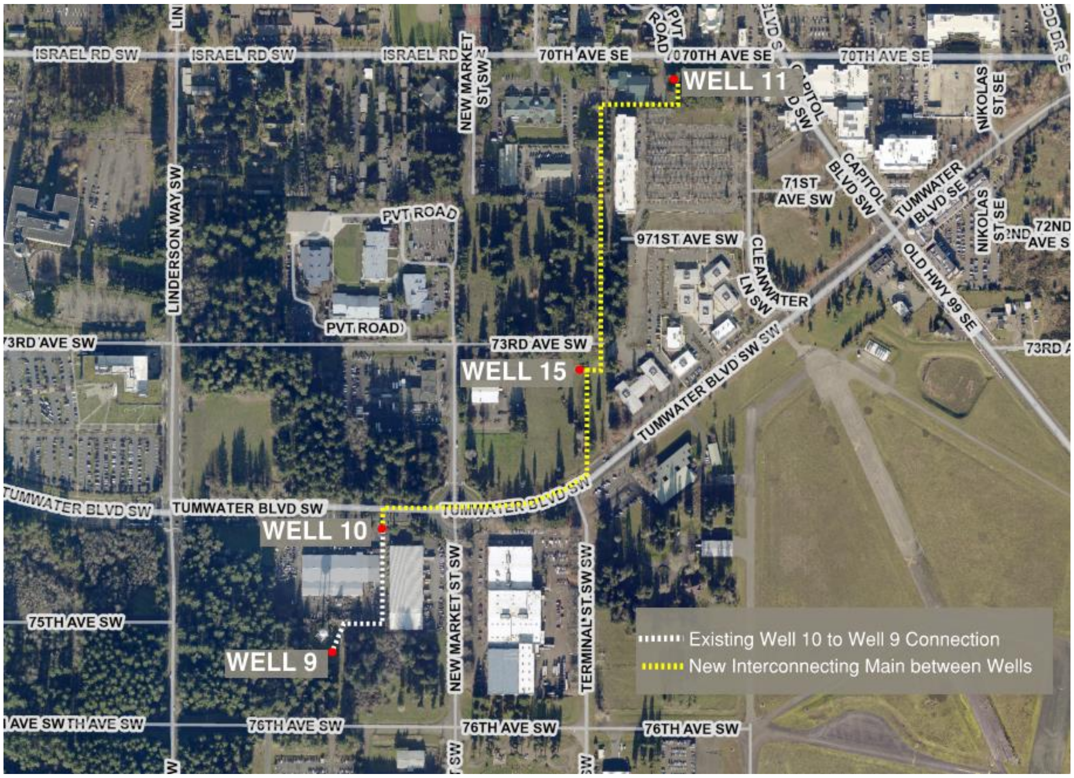


Figure 19. Centralized Treatment Piping

The centralized treatment option (Figure 19) involves routing well water from Well 11 to Well 15, and then from Well 15 to Well 10 where the existing 8-inch line can be reused to bring water to the treatment site at Well 9.

Costs for the implementation of each treatment piping configuration and pH adjustment technology are summarized in Table 9. A breakdown of these budgetary costs are provided in Appendix A.

Table 9. Treatment Implementation Alternatives

Technology	Decentralized	Hybrid	Centralized
Aeration	$2,877,000	$3,650,000	$3,589,000
25% Caustic Soda	$2,746,000	$3,181,000	$3,091,000

6 Summary and Recommendations

The following sections provide a summary of water quality data collected to date and recommendations for optimized corrosion control.

6.1 Wellfield and Treated Water Quality

The difference in wellfield water quality between the Palermo and Bush WTPs and the Airport Wells can be primarily attributed to the differences in treatment. The aeration installed at the Palermo and Bush WTPs results in a higher pH and a more stable corrosion chemistry. Although the Airport Wells have a higher alkalinity, the low pH results in higher DIC values compared to the other water sources. Therefore, the water quality from the Airport Wells pose the greatest corrosion risk in the distribution system.

The water production analysis found that more unaerated/lower pH water is entering the system, which is more corrosive to lead. While no discernable trend could be established with the available data between the presence of unaerated/lower pH water and corrosion, there is extensive published literature showing intermittent exposure to lower pH water can be as bad as, or even worse than, continuous low pH exposure.

Furthermore, minimal blending takes place in the system since the configuration of wells causes water displacement rather than blending to occur. The variable water quality and lack of blending means that the system is by definition not optimized for corrosion control, even though it is in compliance with the LCR.

6.2 Distribution System Water Quality

A review of available distribution system water quality indicates relatively stable corrosion chemistry for most locations with the exception of low pH levels at WQ28 and WQ33 and low chlorine residuals at WQ26. Also, LCR sampling indicates that lead levels are typically below trigger and action levels while copper levels have not exceeded the action level. Thus, copper corrosion is not an issue for the City, and while the City currently complies with the LCR action level of 15 µg/L for lead, the results of this analysis find that the City could exceed the upcoming 10 µg/L trigger levels unless changes are made to the Airport Wells.

6.3 Recommendations

This analysis is based on current operation of the City’s distribution system. However, use of the Airport Wells is expected to decrease as the Brewery Wellfield is developed and brought online in the next five years. The Brewery Wellfield water will be treated with aeration and the water quality concerns associated with intermittent use of the Airport Wells are expected to decline. Based on the data reviewed, HDR recommends implementing the following actions in the event of a 90th percentile action level exceedance and Airport Well usage remains high:

- Airport Wells should be treated with aeration to match the water quality from Palermo and Bush Wellfields to limit the water quality variability between the three wellfields.

Alternatively, the City can increase Airport Well Water pH to that of Bush and Palermo well water through the implementation of treatment with caustic soda.

- Though well usage is not solely based on water quality and is impacted by multiple parameters (production, pressures, groundwater levels), it is encouraged that the City consider limiting usage of the Airport Wells from a solely water quality perspective until treatment can be implemented.

Appendix A. Budgetary Cost Estimate

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Aeration - Decentralized

Description	Quantity	Unit	Unit Cost	Installation	Total Cost (Rounded Up)	Comment
Treatment - Well 11						
8" Ductile Iron Pipe	75	LF	$ 250	$ -	$ 19,000	Piping to aeration treatment.
Aeration equipment	1	EA	$ 67,165	$ 36,940.75	$ 105,000	Vendor quote. Model DB63. Added 55% for installation.
Aeration building	565.5	SQFT	$ 300	$ -	$ 170,000	
					$ 294,000	
Treatment - Well 15						
8" Ductile Iron Pipe	50	LF	$ 250	$ -	$ 13,000	Piping to aeration treatment.
Aeration equipment	1	EA	$ 91,100	$ 50,105.00	$ 142,000	Vendor quote. Model DB86. Added 55% for installation.
Aeration building	870	SQFT	$ 300	$ -	$ 261,000	
					$ 416,000	
Treatment - Well 9/10						
8" Ductile Iron Pipe	90	LF	$ 250	$ -	$ 23,000	Piping to aeration treatment.
Aeration equipment	1	EA	$ 87,547	$ 48,150.85	$ 136,000	Vendor quote. Model DB84. Added 55% for installation.
Aeration building	742.5	SQFT	$ 300	$ -	$ 223,000	
					$ 382,000	
				Subtotal	$ 1,092,000	
				Electrical (25%)	$ 273,000	
				Instrumentation (15%)	$ 164,000	
				Mobilization (10%)	$ 110,000	
				Contractor's Overhead and Profit (15%)	$ 164,000	
				Subtotal	$ 1,803,000	
				Sales Tax (9.5%)	$ 172,000	
				Contingency (50%)	$ 902,000	
				Subtotal Direct Cost	$ 2,877,000	
					$ 2,877,000	

Aeration - Hybrid

Description	Quantity	Unit	Unit Cost	Installation	Total Cost	Comment
Treatment - Well 9/10/15						
8" Ductile Iron Pipe	1550	LF	$ 250	$ -	$ 388,000	Well 15 to Well 10 interconnection
10" Ductile Iron Pipe	100	LF	$ 300	$ -	$ 30,000	Piping to aeration treatment.
Aeration equipment	1	LS	$ 179,320	$ 98,626.00	$ 278,000	Vendor quote. Model DB86. Added 55% for installation.
Aeration building	1320	SQFT	$ 300	$ -	$ 396,000	
			Subtotal		$ 1,092,000	
Treatment - Well 11						
8" Ductile Iron Pipe	75	EA	$ 250	$ -	$ 19,000	Piping to aeration treatment.
Aeration equipment	1	EA	$ 67,165	$ 36,940.75	$ 105,000	Vendor quote. Model DB63. Added 55% for installation.
Aeration building	565.5	SQFT	$ 300	$ -	$ 170,000	
			Subtotal		$ 294,000	
				Subtotal	$ 1,386,000	
				Electrical (25%)	$ 347,000	
				Instrumentation (15%)	$ 208,000	
				Mobilization (10%)	$ 139,000	
				Contractor's Overhead and Profit (15%)	$ 208,000	
				Subtotal	$ 2,288,000	
				Sales Tax (9.5%)	$ 218,000	
				Contingency (50%)	$ 1,144,000	
				Subtotal Direct Cost	$ 3,650,000	
					$ 3,650,000	

Aeration - Centralized

Description	Quantity	Unit	Unit Cost	Installation	Total Cost	Comment
Treatment - Well 9/10/15/11						
4" Ductile Iron Pipe	1800	LF	$ 150	$ -	$ 270,000	Well 11 to Well 15 interconnection
8" Ductile Iron Pipe	1550	LF	$ 250	$ -	$ 388,000	Well 15 to Well 10 interconnection
10" Ductile Iron Pipe	100	LF	$ 300	$ -	$ 30,000	Piping to aeration treatment
Aeration equipment	1	LS	$ 179,320	$ 98,626.00	$ 278,000	Vendor quote. Lowry Model DB86. Two units. Added 55% for installation.
Aeration building	1320	SQFT	$ 300	$ -	$ 396,000	
				Subtotal	$ 1,362,000	
				Electrical (25%)	$ 341,000	
				Instrumentation (15%)	$ 205,000	
				Mobilization (10%)	$ 137,000	
				Contractor's Overhead and Profit (15%)	$ 205,000	
				Subtotal	$ 2,250,000	
				Sales Tax (9.5%)	$ 214,000	
				Contingency (50%)	$ 1,125,000	
				Subtotal Direct Cost	$ 3,589,000	
					$ 3,589,000	

Caustic - Decentralized

Description	Quantity	Unit	Unit Cost	Installation	Total Cost	Comment
Treatment - Well 11						
8" Ductile Iron Pipe	75	LF	$ 250	$ -	$ 19,000	Piping to treatment.
Storage Tank	1	EA	$ 3,000	$ 1,650.00	$ 5,000	300 gal tank. Added 55% for installation.
Metering Pumps	2	EA	$ 6,000	$ 6,600.00	$ 19,000	Added 55% for installation.
Treatment Building	850	SQFT	$ 300	$ -	$ 255,000	
					$ 298,000	
Treatment - Well 15						
8" Ductile Iron Pipe	50	LF	$ 250	$ -	$ 13,000	Piping to treatment.
Storage Tank	1	EA	$ 20,000	$ 11,000.00	$ 31,000	2,700 gal tank. Added 55% for installation.
Metering Pumps	2	EA	$ 6,000	$ 6,600.00	$ 19,000	Added 55% for installation.
Treatment Building	1000	SQFT	$ 300	$ -	$ 300,000	
					$ 363,000	
Treatment - Well 9/10						
8" Ductile Iron Pipe	90	LF	$ 250	$ -	$ 23,000	Piping to treatment.
Storage Tank	1	EA	$ 18,000	$ 9,900.00	$ 28,000	1,600 gal tank. Added 55% for installation.
Metering Pumps	2	EA	$ 9,300	$ 10,230.00	$ 29,000	Added 55% for installation.
Treatment Building	1000	SQFT	$ 300	$ -	$ 300,000	
					$ 380,000	
				Subtotal	$ 1,041,000	
				Electrical (25%)	$ 261,000	
				Instrumentation (15%)	$ 157,000	
				Mobilization (10%)	$ 105,000	
				Contractor's Overhead and Profit (15%)	$ 157,000	
				Subtotal	$ 1,721,000	
				Sales Tax (9.5%)	$ 164,000	
				Contingency (50%)	$ 861,000	
				Subtotal Direct Cost	$ 2,746,000	
					$ 2,746,000	

Caustic - Hybrid

Description	Quantity	Unit	Unit Cost	Installation	Total Cost	Comment
Treatment - Well 9/10/15						
8" Ductile Iron Pipe	1550	LF	$ 250	$ -	$ 388,000	Well 15 to 10 interconnection
10" Ductile Iron Pipe	100	LF	$ 300	$ -	$ 30,000	Piping to treatment.
Storage Tank	1	EA	$ 26,000	$ 14,300.00	$ 41,000	4,300 gal tank
Metering Pumps	2	EA	$ 6,000	$ 6,600.00	$ 19,000	
Treatment Building	1400	SQFT	$ 300	$ -	$ 420,000	
					$ 898,000	
Treatment - Well 11						
8" Ductile Iron Pipe	75	LF	$ 250	$ -	$ 19,000	Piping to treatment.
Storage Tank	1	LS	$ 10,000	$ 5,500.00	$ 16,000	300 gal tank
Metering Pumps	2	EA	$ 6,000	$ 6,600.00	$ 19,000	
Treatment Building	850	SQFT	$ 300	$ -	$ 255,000	
					$ 309,000	
				Subtotal	$ 1,207,000	
				Electrical (25%)	$ 302,000	
				Instrumentation (15%)	$ 182,000	
				Mobilization (10%)	$ 121,000	
				Contractor's Overhead and Profit (15%)	$ 182,000	
				Subtotal	$ 1,994,000	
				Sales Tax (9.5%)	$ 190,000	
				Contingency (50%)	$ 997,000	
				Subtotal Direct Cost	$ 3,181,000	
					$ 3,181,000	

Caustic - Centralized

Description	Quantity	Unit	Unit Cost	Installation	Total Cost	Comment
Treatment - Well 9/10/15/11						
4" Ductile Iron Pipe	1800	LF	$ 150	$ -	$ 270,000	Well 11 to Well 15 interconnection
8" Ductile Iron Pipe	1550	LF	$ 250	$ -	$ 388,000	Well 15 to Well 10 interconnection
10" Ductile Iron Pipe	100	LF	$ 350	$ -	$ 35,000	Piping to treatment.
Storage Tank	1	LS	$ 26,000	$ 14,300.00	$ 41,000	4,500 gal tank
Chemical Metering Pumps	2	EA	$ 6,000	$ 6,600.00	$ 19,000	
Treatment Building	1400	SQFT	$ 300	$ -	$ 420,000	
				Subtotal	$ 1,173,000	
				Electrical (25%)	$ 294,000	
				Instrumentation (15%)	$ 176,000	
				Mobilization (10%)	$ 118,000	
				Contractor's Overhead and Profit (15%)	$ 176,000	
				Subtotal	$ 1,937,000	
				Sales Tax (9.5%)	$ 185,000	
				Contingency (50%)	$ 969,000	
				Subtotal Direct Cost	$ 3,091,000	
					$ 3,091,000	

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