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City of Tumwater Corrosion Control Study

PWS #89700Q

Revised Corrosion Control Study Planning

Tumwater, Washington
December 18, 2023

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Abbreviations

µg	microgram(s)
$CaCO_3$	calcium carbonate
CCT	corrosion control treatment
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.
IOC	inorganic chemicals
L	liter(s)
LCR	Lead and Copper Rule
LCRI	Lead and Copper Rule Improvements
MDD	maximum day demand
mg	milligram(s)
ND	not detected
ORP	oxidation-reduction potential
P90	90th percentile
project report	Washington State Department of Health Project Report
SCADA	supervisory control and data acquisition
State	Washington State
TCE	trichlorethylene
TDS	total dissolved solids
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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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.

1.2 Requirements of the Corrosion Control Study

As the DOH response in Appendix A indicates, the revised corrosion control study is required to evaluate the effectiveness of different treatment options, individually or in combinations, to identify the optimal corrosion control treatment (CCT). This evaluation can be conducted using either analyses based on documented analogous treatment with other systems of similar size, water chemistry, and distribution system configurations, or lacking such information, conducting pipe rig or loop tests, metal coupon tests, or partial-system tests.

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).

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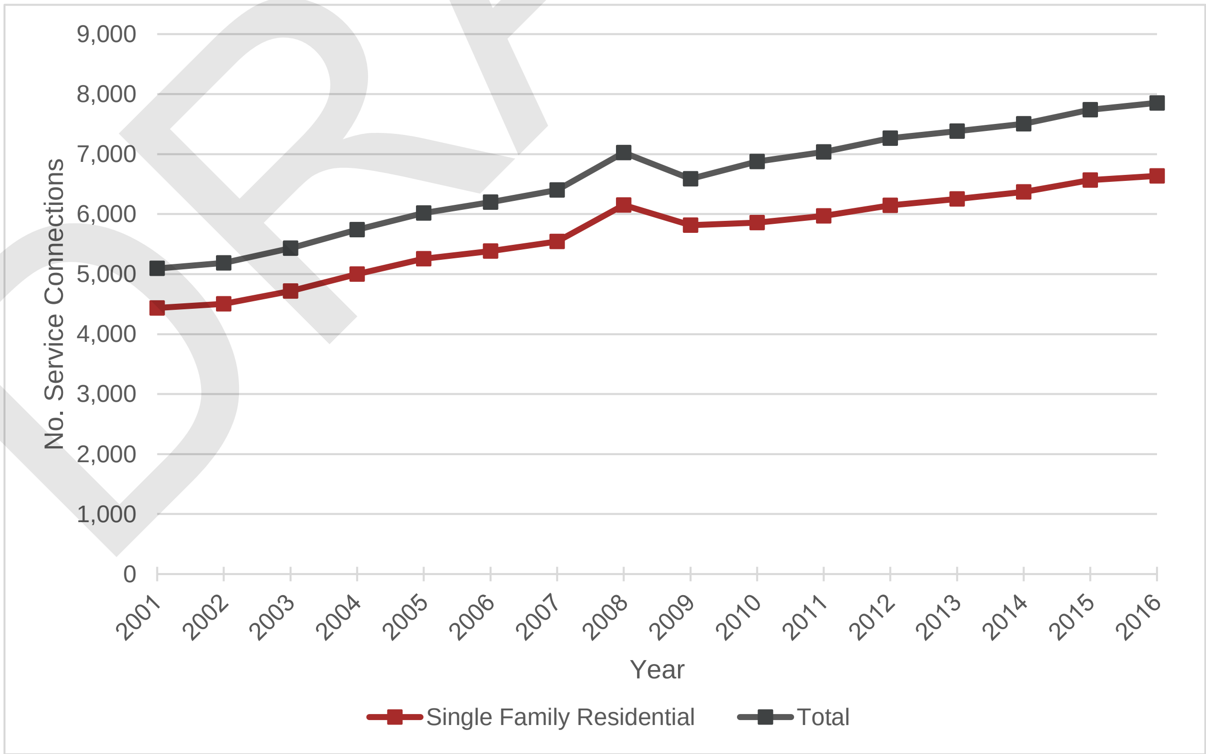

Figure 1. Historical Service Connections Distribution by Customer Type

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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.

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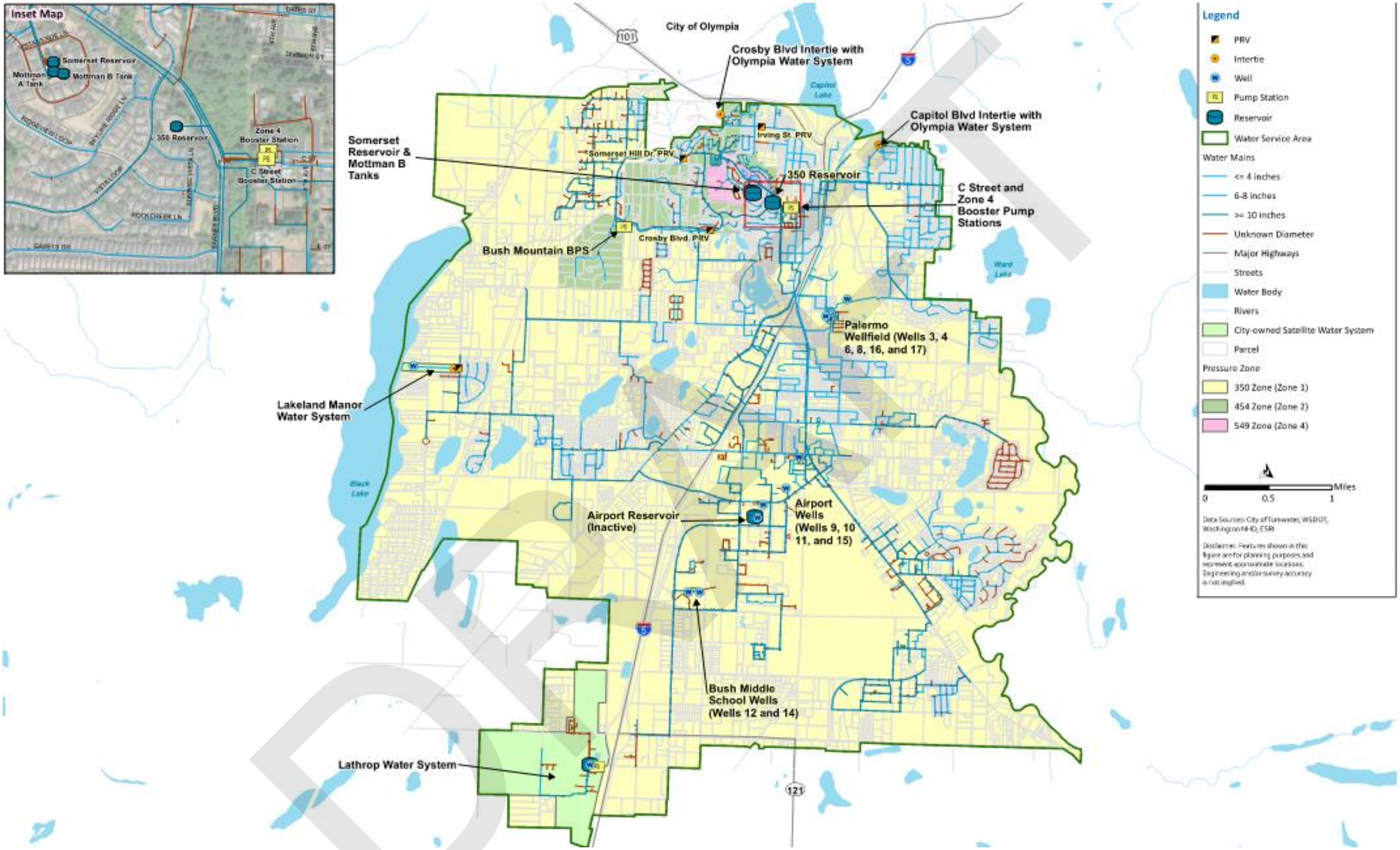

Data Sources: City of Tumwater, WSDOT, Washington NHD, ESRI

Disclaimer: Features shown in this figure are for planning purposes and represent approximate locations. Engineering and/or survey accuracy is not implied.

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

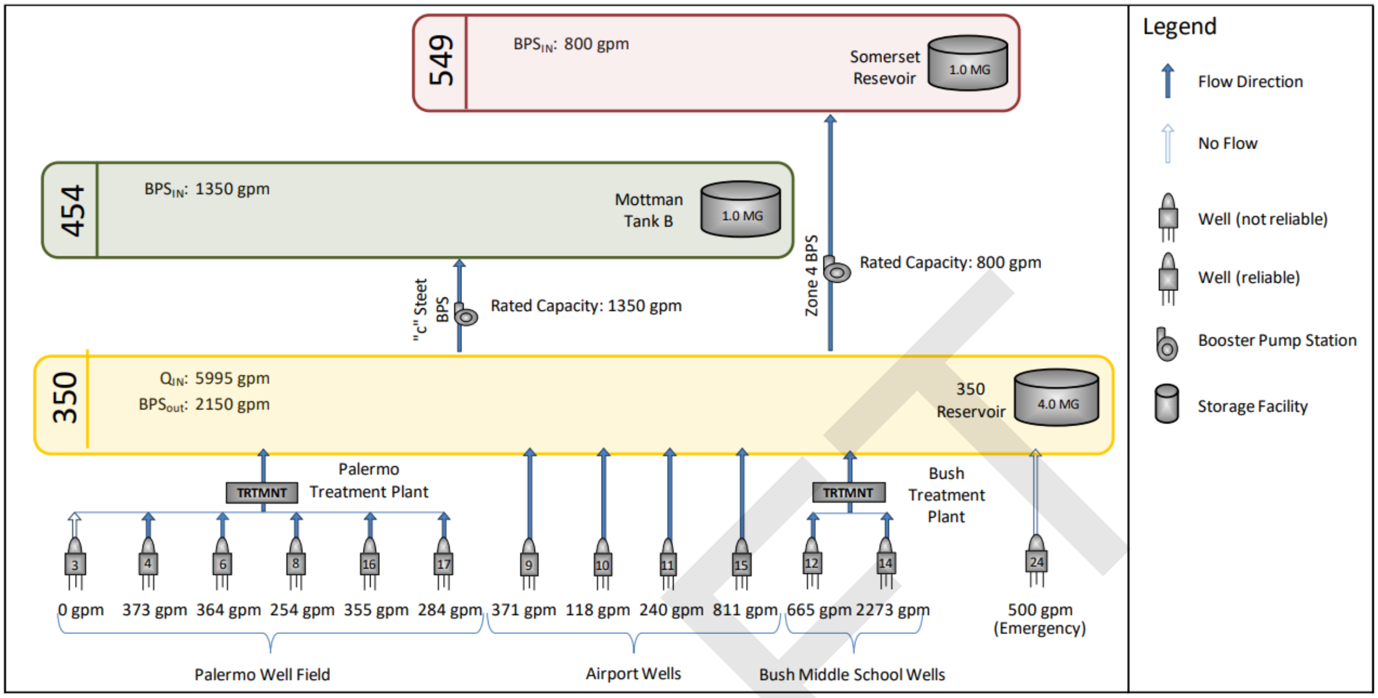

Figure 3. Existing Supply, Pumping, and Storage Configuration
(Source: 2021 Comprehensive WSP Update, Figure 5.1)

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.

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2.1.4 Brewery Wellfield

A new water source, the Brewery Wellfield, is in the planning phase and is expected to be developed over the next five years. During this time, the City will be drilling new wells and testing water quality, including potential treatment methods. The wells will be constructed with a treatment system to reach the City's water quality goals and pH optimization.

3 Water Quality Parameters Impacting Corrosion

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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

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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.

3.1.8 Orthophosphate and Silicate

Orthophosphate is the active agent for phosphate-based corrosion inhibitor chemicals that, when added to water, can bind to the metal to form a very stable scale that resists corrosion. Many groundwaters have naturally occurring orthophosphate.

The effectiveness of orthophosphate depends on many factors including the concentration, pH, DIC and other constituents such as aluminum, iron, and manganese. The EPA’s Optimal Corrosion Control Treatment (OCCT) Technical Recommendations for Primacy Agencies and Public Water Systems document indicates that the pH range across which orthophosphates are most effective for lead and copper corrosion control is between 7.2 and 7.8 and the typical range of orthophosphate concentrations of 1.0 to 3.0 mg/L as PO_4.

Silicate is the active agent for silicate corrosion inhibitor chemicals, which are mixtures of soda ash and silicon dioxide. These chemicals can form metal silicate compounds that serve as anodic inhibitors, inhibiting the oxidation and dissolution of the metal. Silicates may also increase the pH of the water, which may reduce lead and copper release. The effectiveness of silicate inhibitors depends on silicate level, pH, and DIC of the water. Silicate has limited full-scale use for corrosion control as many systems have not considered silicate inhibitors due to lack of research and field information proving its effectiveness, along with estimated operating costs.

Additional information on the addition of phosphate and silicate-based corrosion inhibitors for corrosion control is provided in Section 5.3.

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.

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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. However, there are still sudden drops of pH observed in Figure 4 which are primarily due to recalibration of the probe by staff. This procedure is usually performed every three months or as drifting was identified. The long drift during mid-2020 to late-2021 is likely due to the probe not being calibrated as frequently as many operational and maintenance routines changed due to pandemic safety requirements in place during this time.

The City reached out to the application engineer of Rosemount-Analytical & Detection, the distributor of the chlorine and pH probes used in the City’s analyzers, who stated that drift is not typical and may be due to age, and that a pH sensor is typically good for one to two years. The pH probe in use during the time of these measurements is believed to be installed and manufactured in 2018, which would mean it was two to three years old when the drift was observed. The pH probe has since been replaced, and staff have and will continue maintaining and/or replacing water quality monitoring equipment per manufacturer recommendations.

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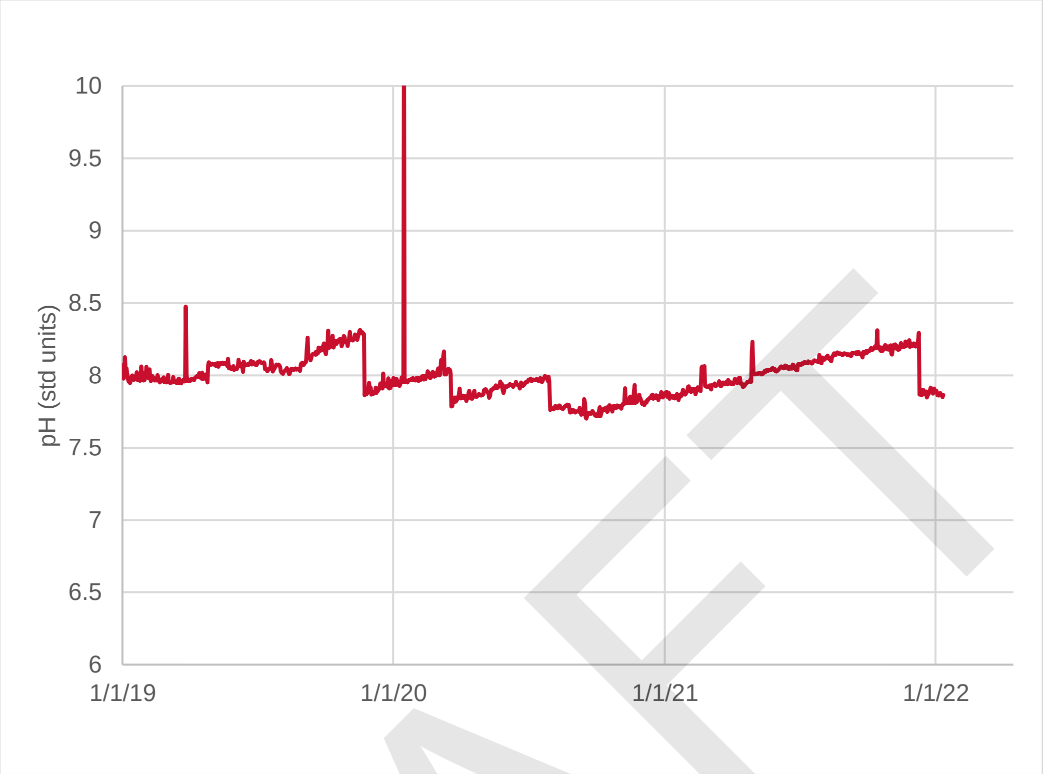

Figure 4. Bush Clearwell SCADA Data – pH (January 2019 to January 2022)

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.

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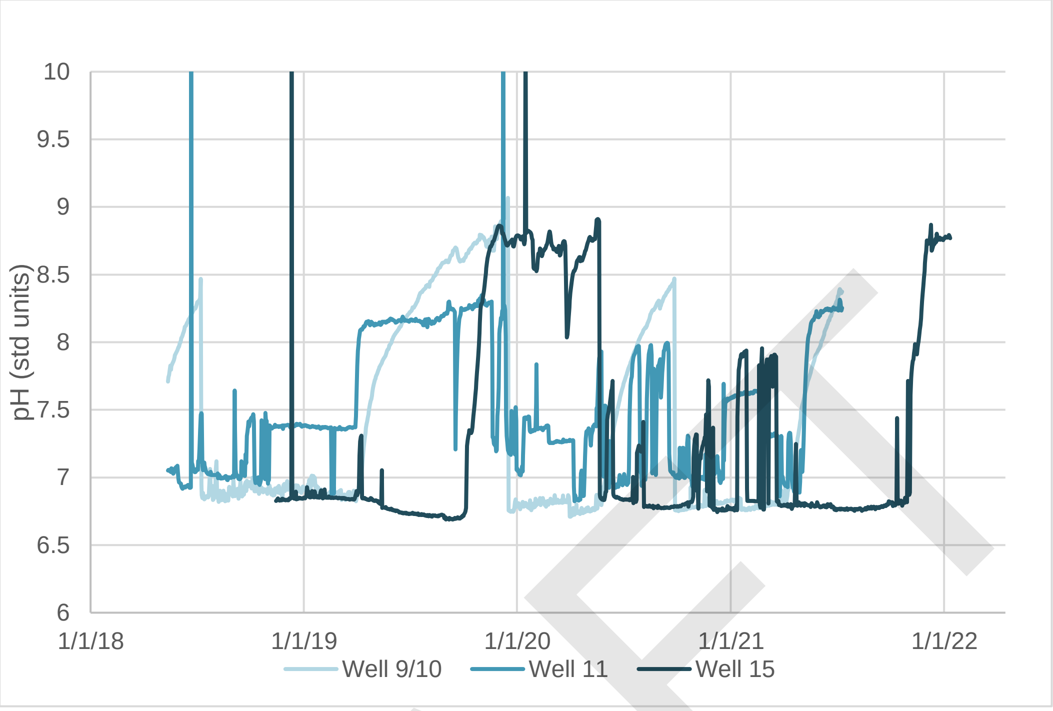

Figure 5. Airport Wells SCADA Data – pH (April 2018 to January 2022)

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.

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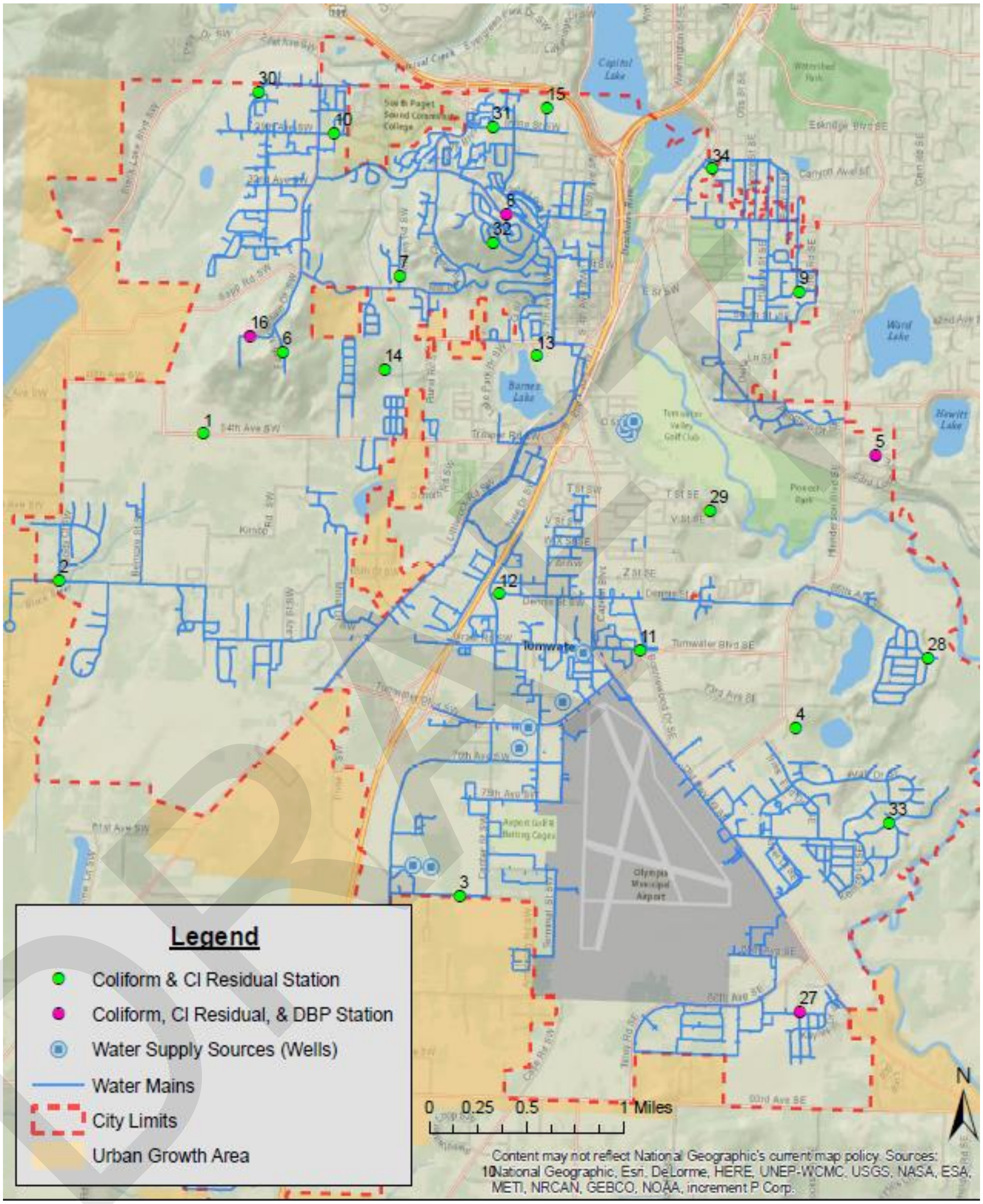

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Figure 6. Sampling Stations in the City's Distribution System (Source: provided with sampling data)

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.

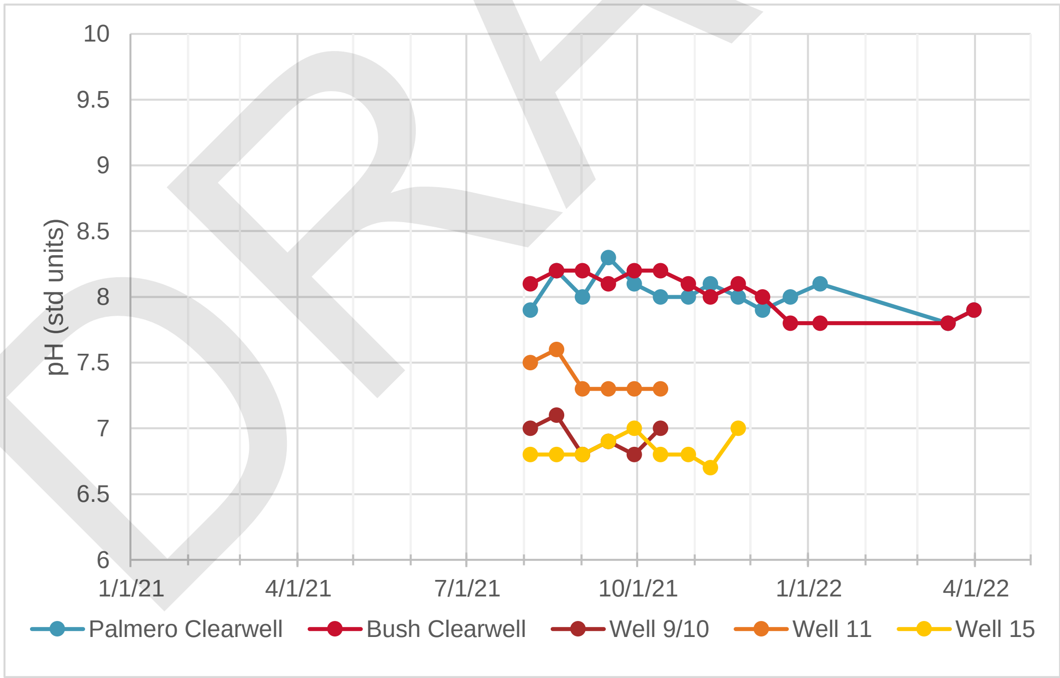

Figure 7. Measured pH, Distribution Entry Points When in Use (August 2021 to March 2022)

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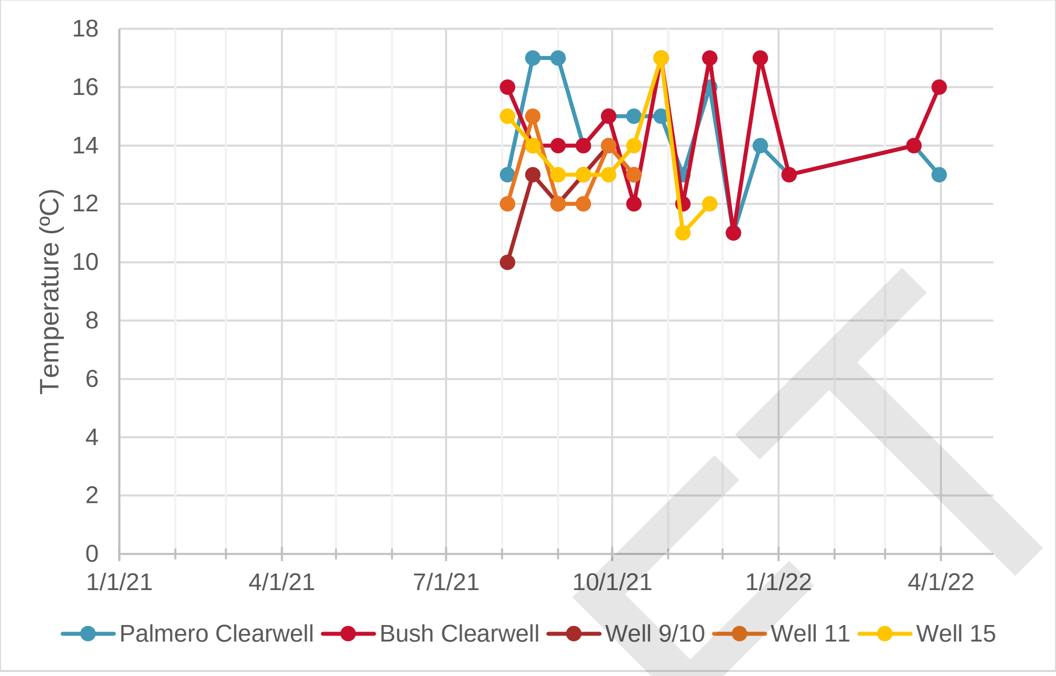

Figure 8. Measured Temperature, Distribution Entry Points When in Use (August 2021 to March 2022)

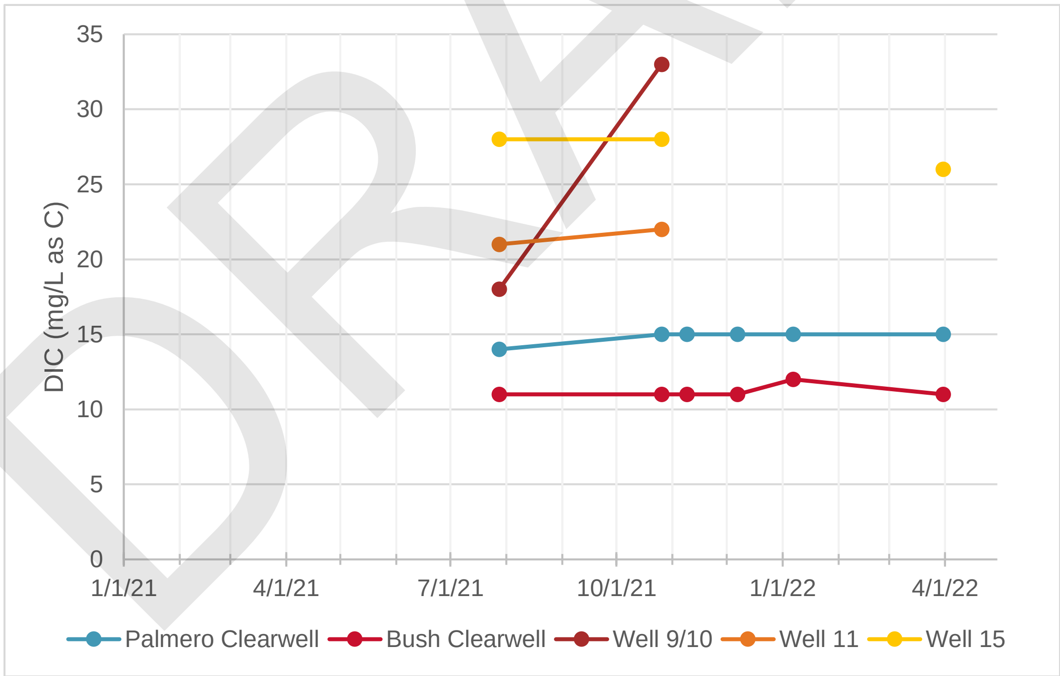

Figure 9. Calculated DIC, Distribution Entry Points When in Use (July 2021 to March 2022)

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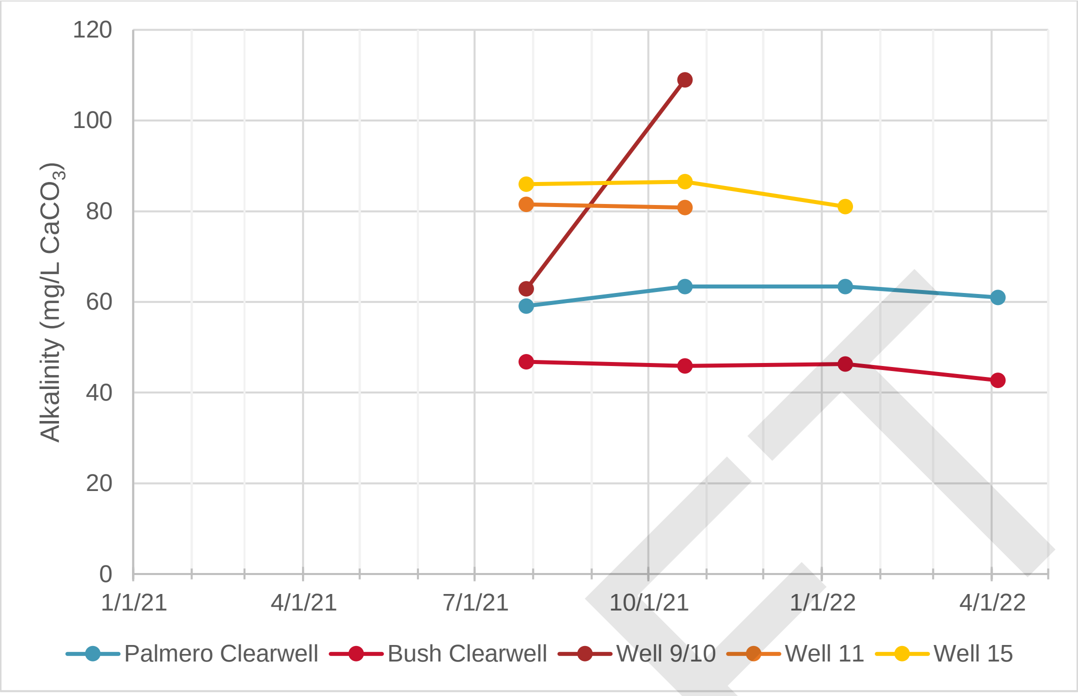

Figure 10. Measured Alkalinity, Distribution Entry Points When in Use (August 2021 to April 2022)

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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.

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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.

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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.

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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.

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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.

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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 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. The EPA is further strengthening the amended LCR with the Lead and Copper Rule Improvements (LCRI) proposed December 6, 2023. The LCRI proposes to lower the lead action level from 15 µg/L to 10 µg/L and eliminate the lead trigger level to simplify the rule.

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 Proposed LCRI Action 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 proposed LCRI lead action 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 concentration that is the proposed LCRI action level, zero were above the proposed action level but less than the current 15 µg/L LCR action level, and three were greater than the current action level.

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

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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

The large drop in lead level between the August and October 2022 sampling dates shown in Table 8 is expected to be a result of sampling being conducted by residents of the homes. The nature of sampling being conducted by volunteers leads to some inconsistencies in the results as evidenced by the data above. For initial samples that had results over 15 µg/L, City staff contacted residents to ask how the sample was collected and confirm the sampling protocol was followed. Two of the samples were either from an inconsistently used faucet or allowed to stagnate over 12 hours. The City resampled to confirm the results and found that all but one site's lead levels returned below 15 µg/L, however, the City noticed that two sample locations on the second round differed from the first.

Table 9 summarizes additional information gathered by the City from residents and the resampling efforts. Overall, resampling demonstrated that some of the homes with higher lead levels detected were more influenced by water stagnation and inconsistent use of faucet.

Table 9. 2022 Follow-Up Sampling Results

Site	Water Sample Date	Stagnation Time (hours)	Lead Result (µg/L)	Sample Location	Sample Comments
Compliance					
A	8/9/2022	6.5	57.9	bathroom sink (downstairs)	
A	10/20/2022	6 to 12	22.4	bathroom sink (downstairs)	Resample; unknown start time but within 6-to-12-hour stagnation.
A	10/20/2022	6 to 12	3.3	kitchen sink (upstairs)	Investigative resample to determine difference between upstairs and downstairs. Unknown start time but within 6-to-12-hour stagnation. Upstairs plumbing was repiped, downstairs is original house plumbing.
B	8/11/2022	8.5	26.6	bathroom sink	
B	10/20/2022	8.5	1.3	kitchen sink	Resample; different faucet.
C	8/16/2022	48	24.9	bathroom sink	48-hour stagnation time.

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Site	Water Sample Date	Stagnation Time (hours)	Lead Result (µg/L)	Sample Location	Sample Comments
C	10/19/2022	9	2.4	bathroom sink	Resample; within proper stagnation time.
Investigative					
D	8/26/2022	6	28.5	kitchen pantry	Not used often but has been prior to stagnation
D	10/20/2022	19.5	ND	kitchen sink	Resample; over 12 hours stagnation; different faucet.

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 proposed LCRI action 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.

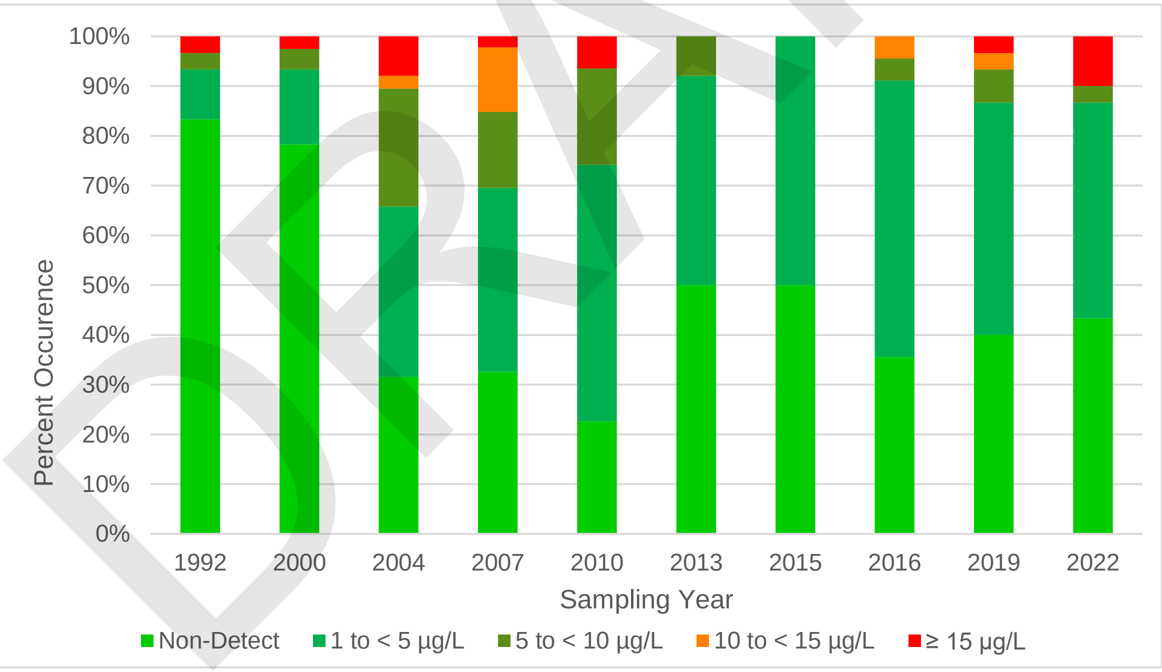

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Figure 11. Lead Sampling Results
(Note: Palermo WTP started 1999, Bush WTP started 2000)

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.

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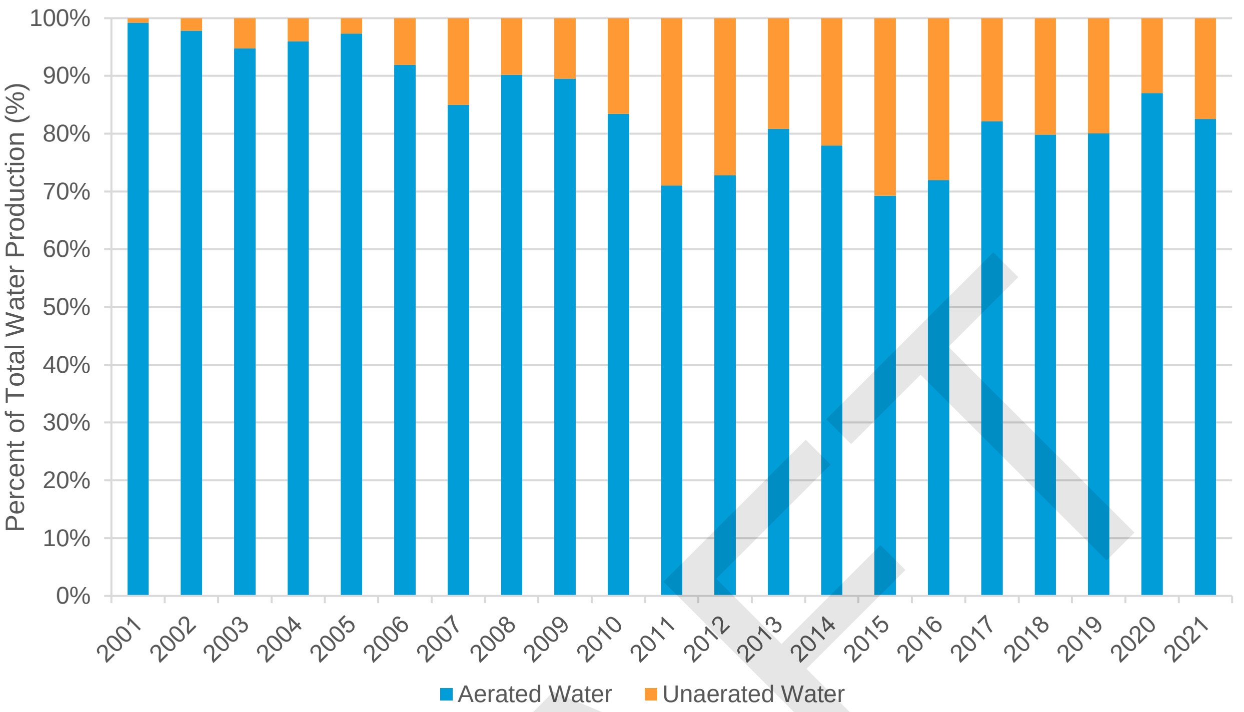

Notes:
- System-wide disinefection began late 2004 with a brief hiatus in 2006.
- Full-time disinfection using sodium hypochlorite has been in operation since 2007

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

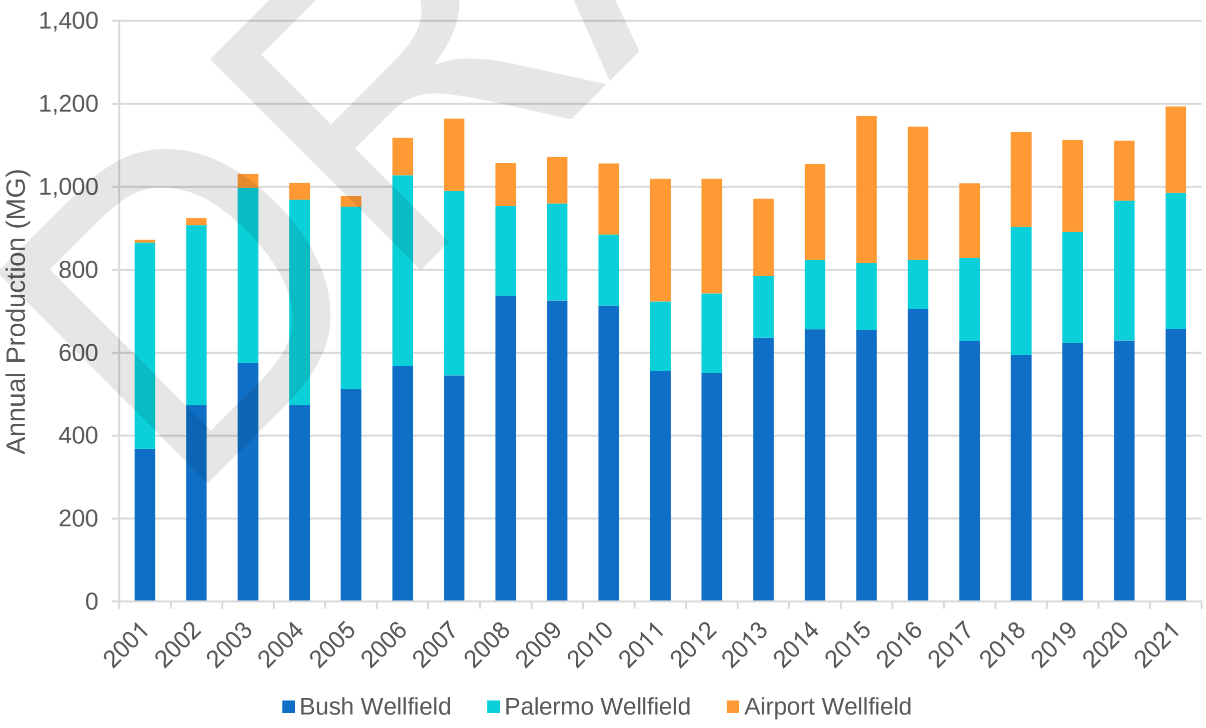

Figure 13. 2001 to 2021 Annual Well Production for Tumwater Water System in MG

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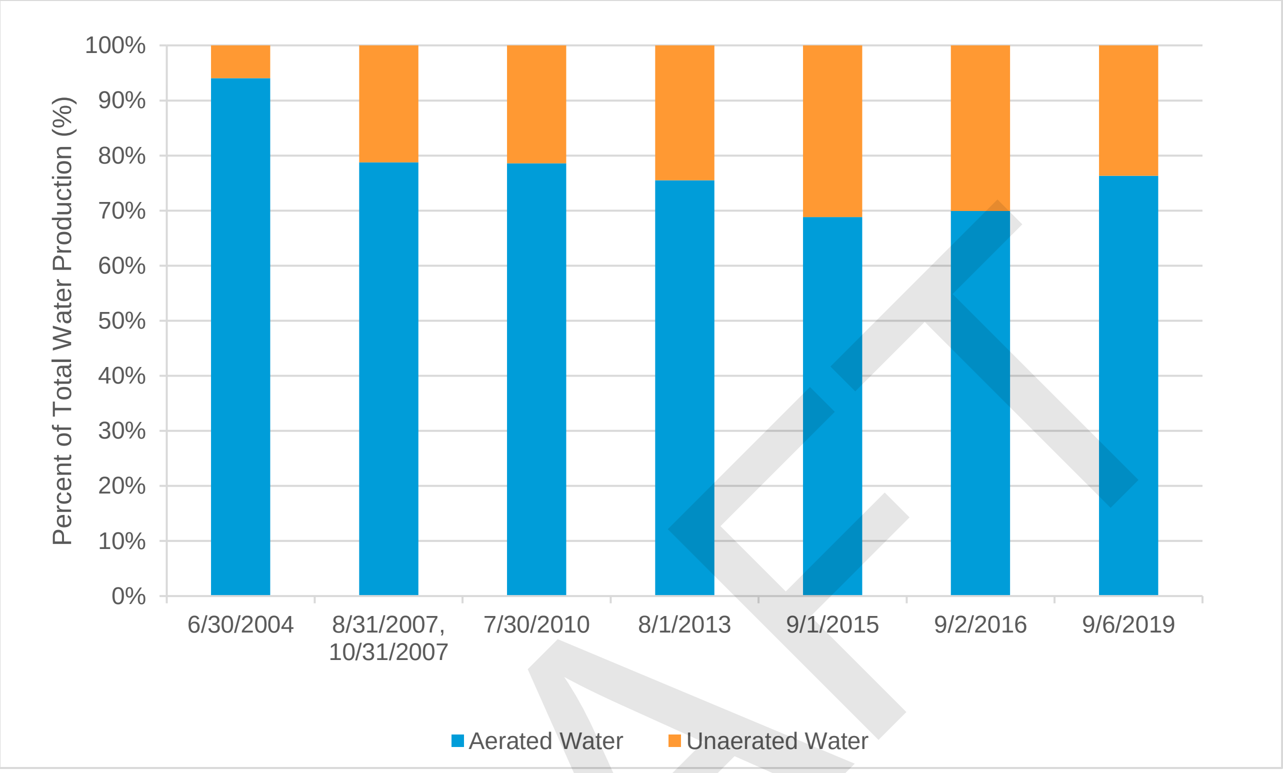

Figure 14. Aerated Water vs Unaerated Water Prior to LCR Sampling

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.

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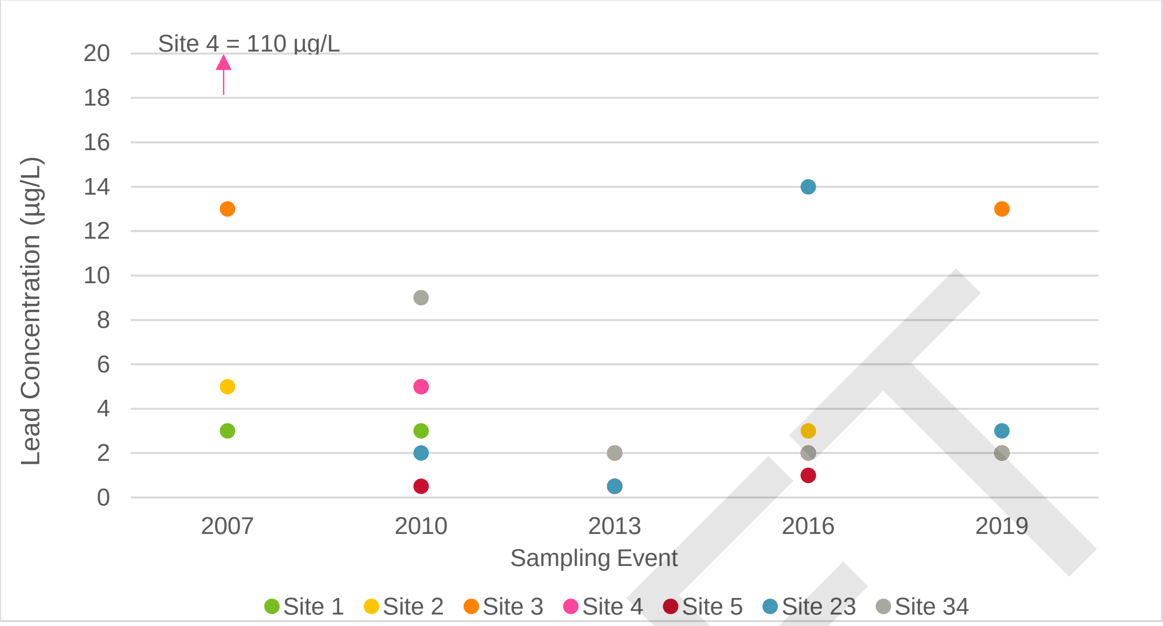

Figure 15. Temporal Analysis of Lead and Copper Sampling Events from 2007 through 2019

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.

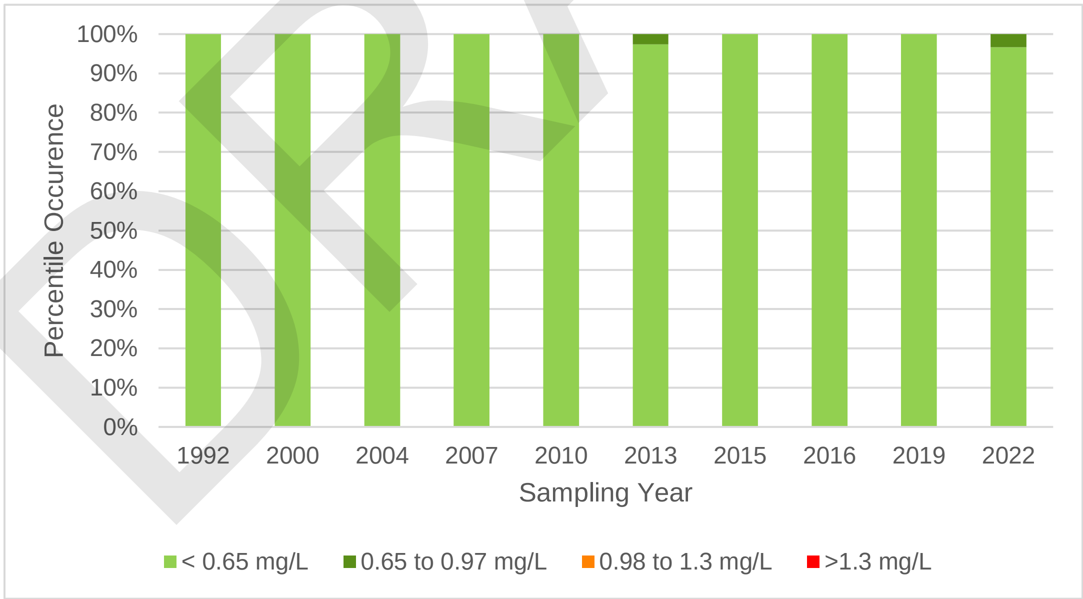

Figure 16. Copper Sampling Results
(Note: Palermo WTP starts 1999, Bush WTP starts 2000)

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5 Corrosion Control Treatment Options

The available CCT options are:

a. pH and alkalinity adjustment.

b. Calcium hardness adjustment.

c. Addition of phosphate or silicate-based corrosion control inhibitors.

This section discusses these options and their potential impacts to the City's water system.

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5.1 pH and Alkalinity Adjustment

A higher pH is beneficial to reducing metal corrosion. The City already implements pH adjustment at the Bush and Palermo Wellfields via the existing aeration systems. Having the City achieve LCR optimization via this CCT option means that the Airport Wells will also have to have pH adjustment. The two most common methods for pH adjustment are using aeration and adding caustic soda into the water. Besides the Bush and Palermo Wellfields, aeration is used extensively in the adjacent City of Olympia's water system as well as many other groundwater-supplied utilities throughout Puget Sound. Adding caustic soda is less common and is used for very large groundwater systems like Tacoma Water's 40 MGD South Tacoma Wellfield as it is more compact that aeration and does not require repumping. However, this approach has more operational risks as caustic soda is a regulated hazardous chemical and requires precise chemical pumping and analytical monitoring systems to prevent over- and under-dosing.

Oftentimes, drinking water pH naturally decreases as the water flows from the treatment systems, through distribution mains and reservoirs, and into customer service lines and premise plumbing. The lower pH by the time the water reaches the customers results in higher corrosion potentials. Increasing the alkalinity at the wells would help the water resist pH changes through distribution, and therefore result in higher pHs and lower corrosion in premise plumbing. Alkalinity adjustment is a common practice in many of the largest Western Washington's water utilities (Bellingham, Everett, Seattle, Tacoma) as much of their supplies is very low alkalinity (<10 mg/L as $CaCO_3$) snowmelt and lake water. HDR is not aware of any groundwater-supplied utilities in Washington that practices alkalinity adjustment. Implementing alkalinity adjustment typically requires the addition of soda ash or lime with carbon dioxide. Soda ash is a dry powder that typically requires dissolution before adding it into water. The combination of lime and carbon dioxide addition is used to simultaneously raise the water pH and increase alkalinity. Both soda ash and lime/carbon dioxide feed systems are complex and operator intensive, which is why it is only used at Western Washington's larger, continuously staffed treatment plants. In addition, these facilities implement alkalinity adjustment to reach up to a target alkalinity of 25 – 45 mg/L as $CaCO_3$, a range that is lower than was detected in the City's groundwater and distribution water.

5.2 Calcium Hardness Adjustment

Calcium hardness adjustment is to deliberately form a thin layer of calcium carbonate, a hard and impervious mineral, over all wetted pipe surfaces. This layer stops water from contacting the pipe metal walls and causing corrosion. HDR is not aware of any groundwater systems in Western Washington (or throughout the Pacific Northwest) that has implemented calcium hardness adjustment as it is often involves lime and carbon dioxide addition. The operational downsides of this type of treatment were described in the prior section. The other issue is that the purposeful formation of calcium carbonate scales is expected to occur on all wetted pipe surfaces. These pipe surfaces include hot water pipes, heaters, and boilers, where such formation can cause clogging and equipment damage. In addition, increasing calcium hardness can interfere with food and beverage production facilities and medical centers, specifically those with dialysis units.

Note that this CCT option was requested by DOH as it is part of the formal LCR language, which this revised corrosion control study is to follow. The promulgated LCRR states that this method of corrosion control has been found to be ineffective and the new rule prohibits its consideration to corrosion control studies.

5.3 Addition of Phosphate and Silicate-based Corrosion Control Inhibitors

Phosphate and silicate-based corrosion control inhibitors are a category of chemicals that bind with metal surfaces to form an insoluble mineral scale. Phosphate is the most common type of corrosion inhibitor used; very few utilities in North America that use silicate-based corrosion control inhibitors due to its high operational cost and limited available supply. There are no Western Washington utilities equal to or larger than the City's that uses phosphates, but there are multiple smaller ones that has implemented it to treat corrosive groundwaters, such as Lake Meridian Water District (Kent, WA) and Olympic View Water and Sewer District (Edmonds, WA).

The LCR does not stipulate what dosages should be evaluated in a corrosion control study. In contrast, the LCRR requires that any study evaluate, at a minimum, the use of 1.0 mg/L and 3.0 mg/L as orthophosphate. There are two types of orthophosphate chemicals specific for corrosion control inhibition: phosphoric acid and zinc orthophosphate. Both compounds are acidic and will depress the water pH. While pH depression increases corrosion, the pH change is typically small as the dose is low, and the benefit of orthophosphate addition more than offsets the impacts of a lower slightly pH. Phosphoric acid is the type used in Western Washington. Zinc orthophosphate is more commonly used in other parts of the country as it also helps with minimizing iron corrosion in old unlined cast iron water mains and stabilizing old asbestos cement pipe, pipe types that are rare in the City's distribution system. Note that there are other phosphate-based corrosion inhibitors, such as polyphosphates and blended phosphates. These inhibitors are specifically meant for controlling iron corrosion and any reduction in lead and copper corrosion is often incidental and low compared to using just phosphoric acid or zinc orthophosphate. As such, polyphosphates and blended phosphates should not be considered for this study.

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The formed phosphate mineral scale has a thickness of microns and does not have the clogging and fouling potential associated with calcium hardness adjustment. In addition, its use normally has little to no effect on food and beverage production facilities or medical centers. The operational downside is that phosphate is a nutrient that can cause biofilm formation, leading to chlorine depletion, nitrification, and coliform detections. This condition is most common in systems with warm (>20 – 25 degrees Celsius) waters and that use chloramines as a distribution system disinfectant, neither of which applies to the City. Another concern is that phosphate and zinc in drinking water will result in elevated concentrations in wastewater. Both constituents, while beneficial for drinking water, are highly regulated nutrients in Puget Sound secondary effluent discharges and can complicate wastewater operations.

6 Review of Analogous Systems

The first step of the treatment evaluation is to review the CCT practices implemented at analogous systems. Analogous water systems are those that are of similar size, water chemistry, and distribution system configurations to the City's. HDR identified the Cities of Olympia and Auburn as such systems to Tumwater. Key parameters of these drinking water utilities are summarized in Table 10 for comparison with the City's system. More description of each system follows the table. The information was gathered from DOH's Sentry database of water system and quality data, consumer confidence reports, water system plans, and corrosion control studies submitted to the DOH. The corrosion control studies submitted to the DOH for the Cities of Olympia and Auburn are provided in Appendix B.

Table 10. Water Quality Characteristics of Analogous Systems

Parameter	Tumwater	Olympia	Auburn
Source Water	Groundwater Only	Groundwater Only	Groundwater Only
No. of Connections	12,682	38,062	24,425
Service Population	30,028	65,360	61,455
Source Water pH	6.7 – 7.6	6.5	6.3 – 6.8
Finished Water pH	Airport: 6.7 – 7.4 (average) Bush and Palermo: 8.0 (avg.)	Target: 7.5 (after aeration)	Target: 7.5 (after aeration)
Source Hardness (mg/L $CaCO_3$)	42 – 82	54 (average)	64 – 169
Source Alkalinity (mg/L $CaCO_3$)	45 – 86	44 – 70	46 - 96

Data Sources:

- Number of connections, service population, and hardness – Sentry database
- All other data: water system plans, corrosion control studies, and consumer confidence reports.

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6.1 City of Olympia

The City of Olympia is physically next to the Tumwater system and owns and operates the McAllister wellfield and six supply wells. Given their proximity to each other, Olympia's groundwater is closest in quality to that of the City's. Table 11 lists the capacities, water pH, and treatment processes for each of their supplies. DOH approved Olympia's corrosion control study in August 2013. That study indicated a target pH throughout the distribution system of 7.5 or greater is considered optimized. The report evaluated aeration in different configurations (aeration tower, diffused bubble aeration, spray nozzle aeration), and caustic addition as potential corrosion control measures. The study found that aeration tower aeration and diffused bubble aeration were both able to adjust the pH above the target level of 7.5.

In general, most of Olympia's permanent water supplies have implemented aeration towers to increase the water pH. The one permanent well without aeration, Indian Summers, produces groundwater at pH 7.6, higher than the distribution system target. The corrosion study had evaluated aeration versus caustic soda and rejected using caustic soda due to its high capital, operational, and maintenance costs.

Table 11. City of Olympia Water Supplies

Water Supply	Use	Capacity (gpm)	Corrosion Control Treatment	2021 Daily Average Treated pH	2022 Daily Average Treated pH
McAllister Wellfield (TW-22, PW-25, PW-25)	Permanent	10,500	Aeration	7.27 to 7.84	7.28 to 7.98
Allison Springs Wells (Well 13, Well 19)	Permanent	1,550	Aeration	7.55 to 7.99	7.25 to 7.90
Shana Park Well 11	Permanent	900	Aeration	7.15 to 7.77	7.50 to 8.00
Indian Summer Well 20	Permanent	670	Not needed	Did not run	Did not run
Hoffman Well 3	Seasonal	900	None	Did not run	Did not run
Kaiser Well 1	Emergency	300	None	Did not run	Did not run

Data Sources:

- Use, capacities, and treatment – Water facility inventory
- pH – 2022 and 2023 water quality reports for 2021 and 2022, respectively. Indian Summer, Hoffman, and Kaiser Wells did not run in this period so there is no data.

Figure 17 shows the areas supplied by each of Olympia's water sources.

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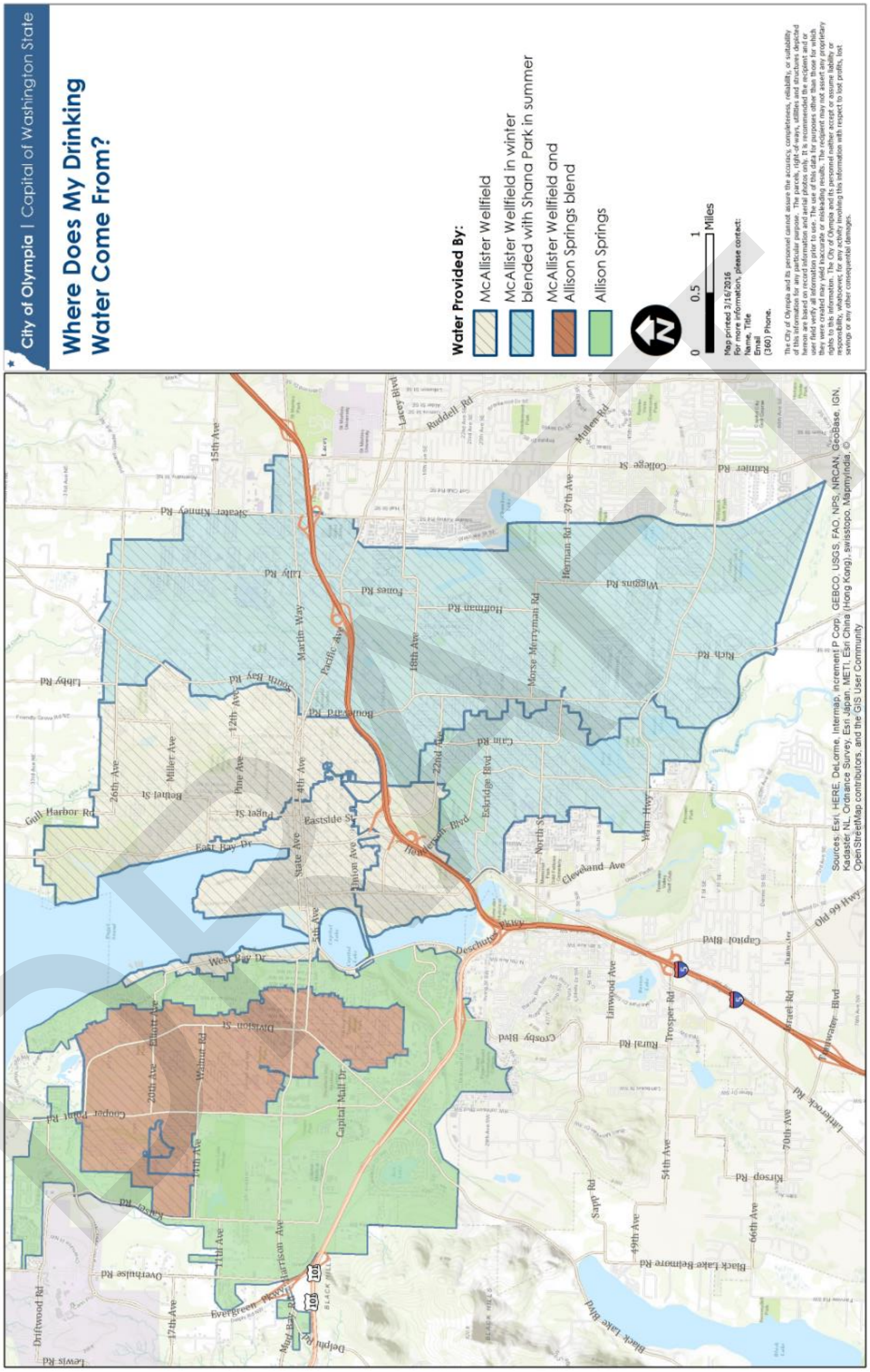

Figure 17. Olympia Water Supply Map

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Olympia's LCR results are summarized in Table 12. The water quality data consists of two periods:

- 2006 to 2015: the period before the full implementation of aeration of the 2013 corrosion control study, and
- 2018 to 2022: the period afterwards.

While Olympia has always been in compliance with LCR requirements, detected lead and copper P90 concentrations were considerably less after aeration was implemented on all required water sources. In addition, Olympia's lead P90 results for 2019 and 2022 are lower than the City's, which were 6 and 9 µg/L for the same years. One key difference is that the City uses a combination of aerated Bush and Palermo groundwater and unaerated Airport Wells whereas all of Olympia's supplies are either aerated or have naturally high pH. Copper results for the two utilities are similar for the same time period.

Table 12. City of Olympia LCR Data

Sampling Year	No. of Samples	Lead P90 (µg/L)	No. of Samples over Lead AL	Copper P90 (mg/L)	No. of Samples over Copper AL
2006	37	3	0	0.99	0
2009	34	6	2	0.91	0
2012	37	5	0	0.90	0
2015	36	7	2	1.20	2
2018	108	3	3	0.14	0
2019	94	1	0	0.11	0
2022	32	4	1	0.72	0

Data Source: Sentry database

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6.2 City of Auburn

The City of Auburn's water system consists of four active wells and two springs. There are two CCT facilities that pH adjust water through aeration: the Fulmer Field CCT Facility and the Howard Road CCT Facility. Table 13 lists each supply and where they undergo CCT, if any, while Figure 18 is a pressure zone map of the system also showing the water supplies. Auburn's CCT is based on a Bilateral Compliance Agreement (BCA) signed with DOH in 1996 and amended in 2000, to address high copper concentrations.

The BCA set forth a staged approach to corrosion control optimization via the implementation of CCT at select sources. The treatment process selected for CCT was to adjust the water pH using aeration. The treatment process selection was informed by the June 1995 Corrosion Control Study Report prepared for Auburn Water System by Economic and Engineering Services, Inc. This report evaluated the applicability of pH/alkalinity adjustment, calcium precipitation, and corrosion inhibitors as corrosion control treatment for the Auburn system. The report found that calcium precipitation was not considered a viable treatment due to low-moderate pH and alkalinity levels and eliminated alkalinity adjustment due to existing alkalinity of Auburn's water falling into the optimal range for copper corrosion control. This left pH adjustment and corrosion inhibitors as remaining viable treatment alternatives.

The report evaluated these two treatment alternatives in detail based on performance, regulatory and function constraints, reliability and operability, and costs. The report found that if Auburn selected pH adjustment for corrosion control treatment, then the use of sodium-based (e.g., caustic soda) may result in unacceptable levels of sodium for certain customers, but other treatment alternatives to increase pH (addition of potassium hydroxide or aeration treatment) are viable options, and if a phosphate-based inhibitor is selected for corrosion control, then disinfection treatment and phosphate addition may be needed for every source to maintain a uniform phosphate concentration in the distribution system. Treatment may not be required for every source if pH adjustment is selected.

It was also found that use of a phosphate-based inhibitor would need to be accompanied by an increase in pH. Therefore, pH adjustment via aeration was selected as it was the most cost effective and aligned closely with the Auburn system's existing operations and future plans for water quality improvement.

The BCA required Auburn to implement CCTs for Wells 2, 6, and 7. These supplies were combined and treated at the Fulmer Field CCT Facility that started operations in 2002. If implementing CCT for these sources had not successfully reduced lead and copper corrosion, then Auburn would have also needed to implement Stage 2 of the BCA which required treatment for Well 4. If implementation of Stage 2 was unsuccessful in reduction of lead and copper corrosion, then Auburn would need to implement Stage 3 of the BCA which required treatment for West Hill Springs. The need to implement Well 4 CCT has never been triggered and thus the BCA was successful after Stage 1. The Howard Road CCT Facility began operation to treat water from Coal Creek Spring and Well 1. The supplies without treatment are Well 4, West Hill Springs, and five inactive and emergency wells.

Table 13. City of Auburn Water Supplies

Water Supply	Use	Capacity (gpm)	Corrosion Control Treatment Processes
Well 2	Permanent	2,000	Aeration at Fulmer Field Corrosion Control Treatment Facility
Well 6	Permanent	2,200	
Well 7	Inactive	0 (no pump)	
Coal Creek Spring	Permanent	3,500	Aeration at Howard Road Corrosion Control Treatment Facility
Well 1	Permanent	2,100	
Well 4	Permanent	2,600	Aeration to be added if Stage 2 treatment required. Not Needed.
West Hill Springs	Permanent	600	Aeration to be added if Stage 3 treatment required. Not Needed.
Well 5	Inactive	650	None
Well 5A	Inactive	180	None
Well 3A	Emergency	0	None
Well 3B	Emergency	0	None
Well 5B	Emergency	0	None

Data Source: Water facility inventory

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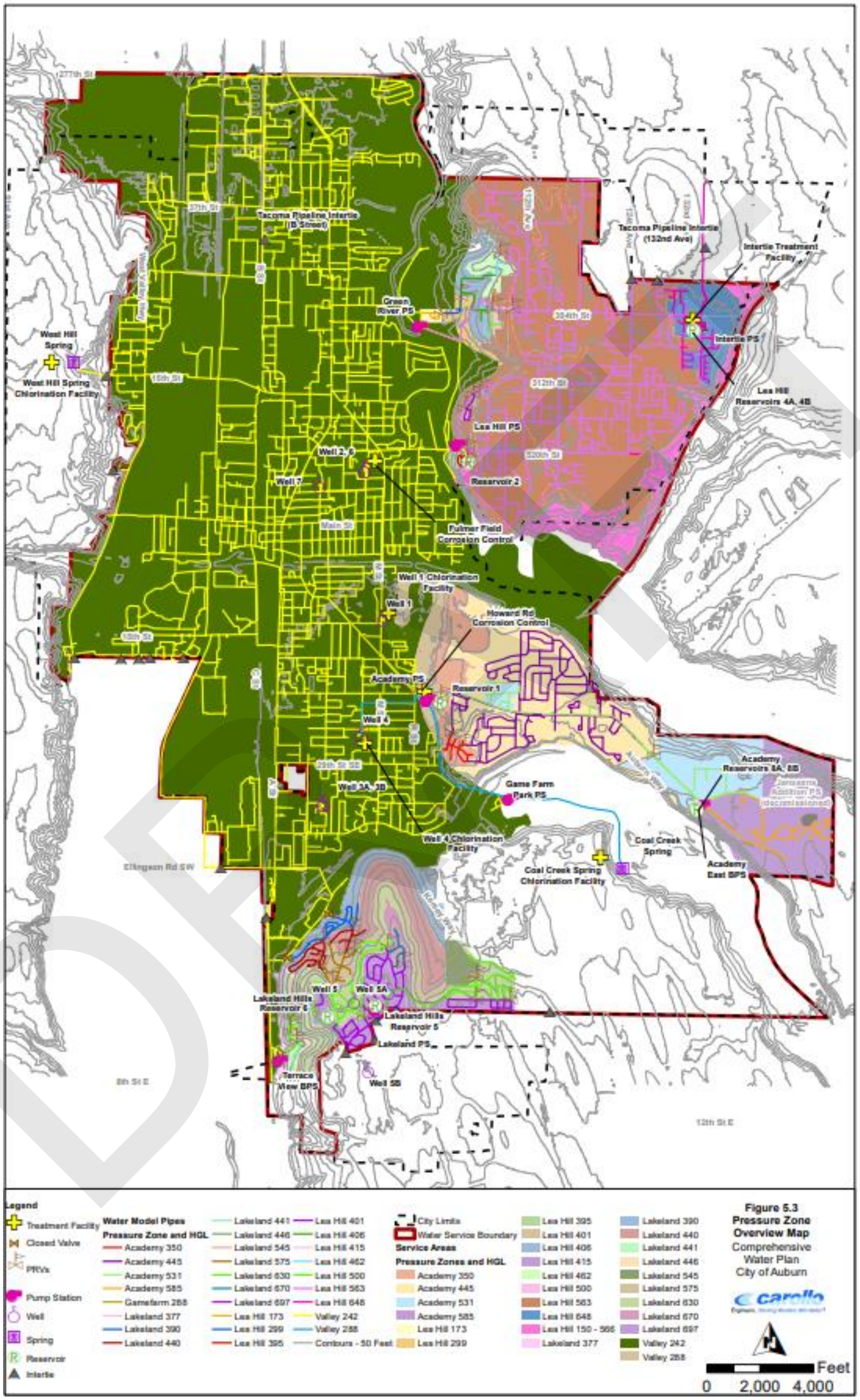

Figure 18. City of Auburn Pressure Zone Map Also Showing Water Supplies

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Auburn's LCR results back to 2003 are summarized in Table 14. P90 lead and copper concentrations for Auburn are generally lower than those of the City's for the entire period analyzed.

Table 14. City of Auburn LCR Data

Sampling Year	No. of Samples	Lead P90 (µg/L)	No. of Samples over Lead AL	Copper P90 (mg/L)	No. of Samples over Copper AL
2003	50	2	1	0.24	0
2004	11	5	0	2.64	1
2005	34	2	0	0.65	0
2006	33	3	0	0.47	0
2009	33	8	1	0.38	0
2012	32	2	1	0.37	0
2015	31	2	1	0.17	0
2018	32	1	0	0.18	1
2020	71	3	1	0.12	0
2021	50	1	0	0.08	0

Data Source: Sentry database

DRAFT

6.3 Summary of Analogous System Review

Review of the available Olympia and Auburn data found that:

1. Implementing aeration for all low pH water sources increased the distribution system pH to a higher, more consistent value.
2. The increased water pH of 7.8 – 8.0 has resulted in lower P90 lead and copper concentrations that are lower than the values the City has historically found in its system.
3. Use of aeration alone was sufficient to achieve their respective lower P90 corrosion results. Neither Olympia nor Auburn used caustic soda or a phosphate-based corrosion inhibitor as a CCT. When it came to making the decision on CCT method installed, both Olympia and Auburn considered caustic soda for pH adjustment, but ultimately selected pH adjustment via aeration. Auburn also evaluated the use of a phosphate-based corrosion inhibitor, but still found pH adjustment via aeration to be the best path forward due to the use of a phosphate-based corrosion inhibitor requiring pH adjustment and requiring treatment at all sources.
4. There were no regularly used supplies that had water pHs as low as the Airport Well groundwater.

With the City's permission, HDR will contact Olympia to obtain a copy of their approved 2013 corrosion control study and Auburn for any documentation relating to the 1996/2000 BCA to provide background on why aeration was selected over other CCTs.

However, this added data by itself maybe insufficient to address DOH's concerns regarding the City's corrosion potential. Specifically, DOH's position is that the City's historical variable P90 lead concentrations did not correspond to historical usage of unaerated Airport Wells groundwater versus the aerated Bush and Palermo groundwaters. As a result, there could be a need to provide treatment beyond aeration alone to be considered optimized.

7 Treatment Recommendation

The EPA's OCCT guidance document provides flowcharts to select the best CCT options based on source water quality. Flowchart 1a shown in Figure 19 is provided as guidance for selecting treatment to address lead only or both lead and copper with finished water pH < 7.2. This flowchart applies to Well 9/10 with an average finished water pH of 6.9 and a DIC of 26 mg/L as C and Well 15 with a pH of 6.8 and DIC of 27 mg/L as C. Since both wells exhibit a DIC greater than 15 mg/L as C, the best path forward as indicated by the chart is to raise the pH in 0.25-unit increments using soda ash, potash, caustic soda, or aeration; or adding orthophosphate to raise the pH to 7.2 to 7.8.

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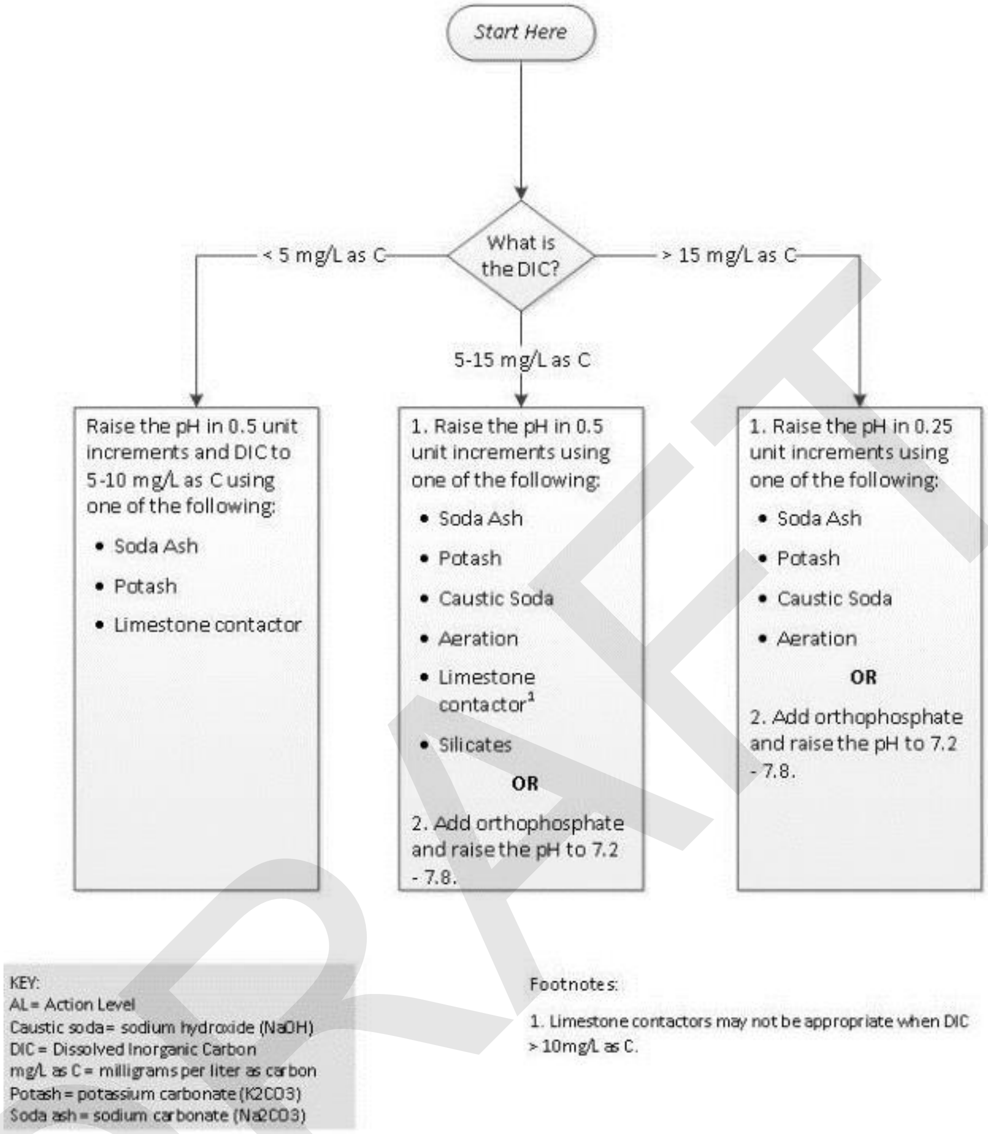

Figure 19. Flowchart 1a: Selecting Treatment for Lead only or Lead and Copper with pH < 7.2 (EPA's OCCT Guidance)

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Based on this initial review and following the flowcharts provided in EPA's OCCT guidance document, the initial recommendations, in order of priority, for subsequent treatment evaluation are:

1. Aeration of Airport Wells groundwater to pH 7.8 – 8.0, the same pH as the Bush and Palermo groundwaters. This option is the priority as it involves implementing processes that the City already uses and is familiar with. It also does not require the storage and use of hazardous chemicals.
2. Addition of caustic soda to the Airport Wells groundwater to adjust pH to 7.8 – 8.0, the same pH as the Bush and Palermo groundwater. This option is less desirable than pH adjustment with aeration as it requires the storage and use of

hazardous chemicals. This process will require new chemical feed systems, controls, and buildings installed at the Airport Wells.

These recommendations are further evaluated in Section 8.

In the event pH adjustment of the Airport Wells groundwater to pH 7.8 – 8.0 does not result in system corrosion control treatment optimization, corrosion control technique will be re-evaluated to consider lower priority options including:

- Aeration of Airport Wells groundwater and addition of caustic soda to further increase the treated water pH to pH 8.2 – 8.4 at all wellfields. This process will require new chemical feed systems, controls, and buildings installed at all locations. The pH of 8.2 – 8.4 is selected as it is an incremental increase above pH 7.8 – 8.0 and generally matches the pH of the largest water systems in the state (Seattle Public Utilities, Tacoma Water, Everett Public Works).
- Aeration of Airport Wells groundwater and addition of phosphoric acid to all groundwaters, including the Bush and Palermo groundwaters. This option has the lowest priority as the addition of phosphoric acid requires implementation at all wellfields to be effective and will require discussions with LOTT Clean Water Alliance as additional phosphate concentrates in wastewater can pose a compliance issue for the Budd Inlet Wastewater Treatment Plant.

The other CCT options were rejected for the following reasons:

- Calcium hardness adjustment is difficult to operate and causes impacts to several of the City’s important customers. This adjustment requires larger and more complex equipment and buildings compared to adding phosphoric acid or caustic soda. Finally, this option is a much more labor-intensive process.
- Zinc orthophosphate provides no added benefit to the City compared to phosphoric acid and can result in negative impacts to wastewater treatment systems.
- Silicate-based corrosion inhibitors are expensive and provide no additional benefits compared to phosphoric acid.

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8 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 poses 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 pH adjustment of the Airport Wells groundwater to a pH of 7.8 to 8.0 through aeration or the addition of 25% caustic soda.

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 20 to Figure 22 .

Figure 20. Decentralized Treatment Piping

The decentralized treatment option (Figure 20) maintains the existing operation of the Airport Wells and includes treatment at each well site (Wells 9/10, Well 15, and Well 11).

Figure 21. Hybrid Treatment Piping

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The hybrid treatment option (Figure 21) 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.

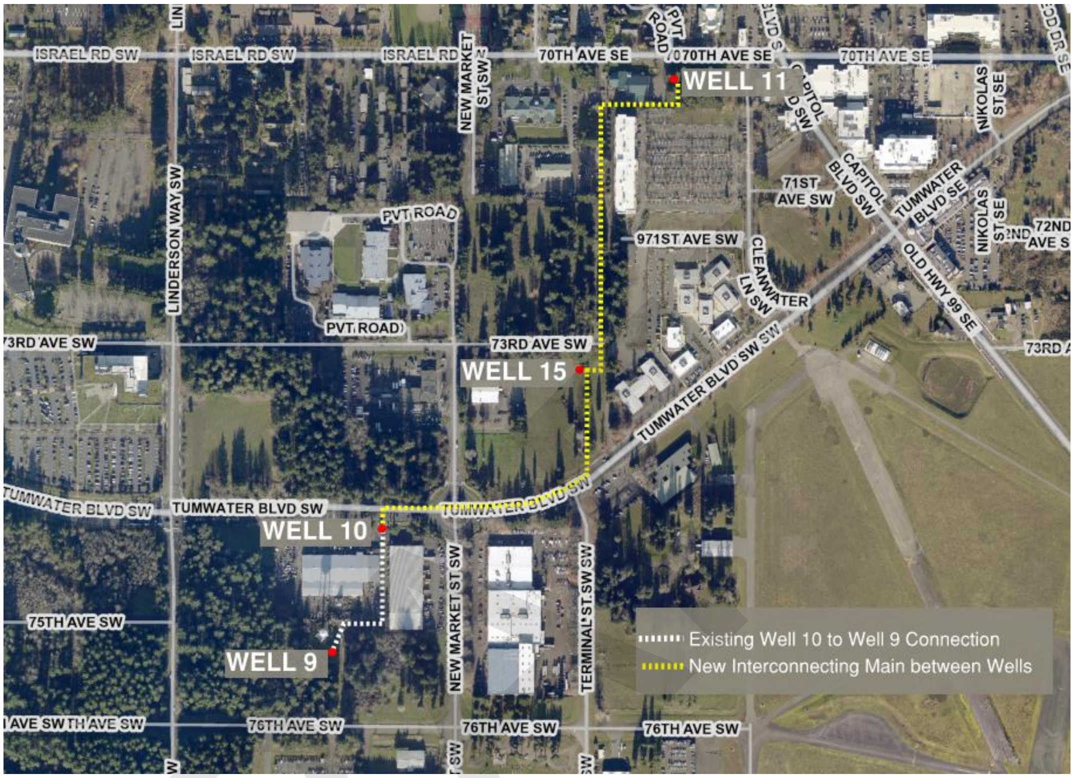

Figure 22. Centralized Treatment Piping

The centralized treatment option (Figure 22) 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 15. A breakdown of budgetary costs is provided in Appendix C.

Table 15. 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

After further review, the City proposes moving forward with pH adjustment of the Airport Wells groundwater by implementing decentralized aeration in a staged approach. This approach is detailed in Section 9.4.

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9 Summary and Recommendations

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

9.1 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 poses 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.

9.2 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 LCRI action level unless changes are made to the Airport Wells.

9.3 Operations

A review of historical pH data show that pH analyzers may not be accurately monitoring pH due to instrumentation issues. The City has addressed pH monitoring concerns and will continue regularly calibrating pH analyzers and maintaining and or replacing pH probes and analytical equipment per the manufacturer’s recommendations.

9.4 Recommendations

This analysis is based on current operation of the City’s distribution system where there is no corrosion control in place at the Airport Wells and use of these wells is limited to seasonal peaking. However, the City anticipates a large water consumer to come online in the next five years requiring more reliance on these wells year-round. To optimize the

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City's corrosion control treatment program, it is recommended that the City implement decentralized aeration to the Airport Wells in a staged approach as summarized in Table 16.

Table 16. City's Proposed Staged Approach to OCCT

Source	Stage
Airport Well 15	1
Future Sources (Brewery Wellfield)	1
Airport Wells 9/10	2, if needed.
Airport Well 11	No treatment. This is already above the desired 7.0 pH for corrosion control with a pH of 7.4.

During stage 1, pH adjustment via aeration will be installed at Airport Well 15 to match the water quality from Palermo and Bush Wellfield to limit water quality variability between the three wellfields. Well 15 is the largest producer of the Airport wellfield and used more consistently throughout the year. Well 15 also is the well with the lowest source water pH of 6.8. Corrosion control treatment for Well 15 has been proposed in the City Capital Facilities Plan for 2024 – 2029. If accepted, the project is scheduled to start in 2025.

Stage 1 will also include planning, design, and construction of the Brewery wellfield along with a treatment system constructed to reach the City's water quality goals and pH optimization.

Following the implementation of stage 1, monitoring will be conducted to determine if optimization is achieved. If optimization is achieved, no further treatment is needed. If optimization is not achieved, the City plans to evaluate aeration treatment for Airport Wells 9 and 10. If the system still remains unoptimized after the implementation of stage 2 treatment, corrosion control treatment technique will be re-evaluated.

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Appendix A.
DOH Response Letter
February 2, 2023

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STATE OF WASHINGTON
DEPARTMENT OF HEALTH
SOUTHWEST DRINKING WATER REGIONAL OPERATIONS
111 Israel Road Southeast • PO Box 47823 • Olympia, Washington 98504-7823
Tel: (360) 236-3030 • Fax: (360) 236-3029 • TDD/TTY 711

February 2, 2023

Steven Craig
City of Tumwater
555 Israel Road Southwest
Tumwater, Washington 98501

Subject: City of Tumwater, ID #89700Q, Thurston County; Corrosion Control Study, ODW Project #22-1201

Dear Steven Craig:

The submittal we received on December 2, 2022, has been reviewed in accordance with the provisions of WAC 246-290. We have reviewed the data and require additional information to meet the requirements of a Corrosion Control Study as described in 40 CFR 141.82(c).

The purpose of the Corrosion Control Study is to perform a system wide evaluation of corrosion control options to identify the most appropriate method for your system. The submittal notes the Palermo and Bush wells have aeration systems for pH adjustment that have been in operation for over 20 years. In this time the City of Tumwater has seen 90th percentile lead values below the Action Level (AL), but still too high to be considered optimized. There were also several sites with lead levels significantly above the AL. The higher lead levels were not associated with increased use of the untreated Airport Well sources. This suggests further study of the effectiveness of the current corrosion control treatment methods is needed in addition to the recommendation for the untreated sources. **Please submit a revised Corrosion Control Study by August 2, 2024.**

In the revised study, you must do the following to meet the requirements of 40 CFR 141.82(c):

1. Evaluate the effectiveness of the following treatments or combinations of treatments to identify the optimal corrosion control treatment for your system:
    a. pH and alkalinity adjustment.
    b. Calcium hardness adjustment.
    c. Addition of phosphate or silicate based corrosion control inhibitors.
2. Evaluate these corrosion control treatment methods using either pipe rig or loop tests, metal coupon tests, partial-system tests, or analyses based on documented analogous treatment with other systems of similar size, water chemistry, and distribution system configurations.
3. Measure lead, copper, pH, alkalinity, calcium, conductivity, inhibitor concentration (if used), and water temperature in any testing conducted to evaluate the treatments listed above.
4. Identify all chemical or physical constraints that limit or prohibit the use of a particular corrosion control treatment and document such constraints with at least one of the following:
    a. Data and documentation showing that a particular corrosion control treatment has adversely affected other water treatment processes when used by another water system with comparable water quality characteristics; and/or

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   b. Data and documentation demonstrating that the water system has previously attempted to evaluate a particular corrosion control treatment and has found the treatment is ineffective or adversely affects other water quality treatment processes.

5. Evaluate the effect of the chemicals used for corrosion control treatment on other water quality treatment processes.
6. Recommend in writing the optimal corrosion control treatment option for your system based on the data generated during the evaluation. Provide a rationale for the recommendation along with all supporting documentation.

Please ensure the revised study also addresses the two minor comments below:

1. Section 4.1. Verify that pH analyzers are being calibrated at the manufacturer's recommended frequency. In Figure 4, please explain the upward drift in pH followed by drops.
2. Section 4.3. Explain the large drop in lead level between the August and October 2022 sampling dates show in Table 8.

You need to have a professional engineer (licensed in the State of Washington) complete the Corrosion Control Study using current source and distribution water quality data. We recommend using the EPA *Optimal Corrosion Control Treatment Evaluation Technical Recommendations* as guidance in completing the study. Please reference our letter dated August 14, 2019, for an outline of the next corrosion control steps for your system.

Our approval of your water system design does not confer or guarantee any right to a specific quantity of water. The approved number of service connections is based on your representation of available water quantity. If the Department of Ecology, a local planning agency, or other authority responsible for determining water rights and water system adequacy, determines you have use of less water than you represented, the number of approved connections may be reduced commensurate with the actual amount of water and your legal right to use it.

WAC 246-290-990 establishes a schedule of fees for review of planning, engineering, and construction documents. An itemized invoice showing the amount due of $408 is enclosed.

If you have any questions, please contact me at (564) 669-3170 or by e-mail at candida.granillo-dodds@doh.wa.gov.

Sincerely,

Candida Granillo Dodds

Candida Granillo-Dodds, P.E.
Office of Drinking Water, Regional Engineer

cc: Carrie Gillum, City of Tumwater
Pierre Kwan, HDR
Thurston County Public Health & Social Health Services
Sophia Petro, ODW

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STATE OF WASHINGTON
Department of Health
OFFICE OF DRINKING WATER
Project And Plan Review

INVOICE

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ACCOUNTS PAYABLE
TUMWATER CITY OF
555 ISRAEL RD SW
TUMWATER, WA 98501

WS ID: 89700
Invoice No: 50990
Invoice Date: 02/01/2023
Due Date: 03/03/2023

WS NAME: TUMWATER CITY OF

PROJECT AND PLAN REVIEW SUBMITAL#: 22-1201

DESCRIPTION	QTY	COST	AMOUNT
Other Reviews	1	x $408.00	$408.00
		Total Amount Due	**$408.00**

Comments: Corrosion Control Study

1. ***Pay online*** with a credit card, debit card, or electronic check (ACH) using the Environmental Health Payment System at https://secureaccess.wa.gov/.
2. For billing questions, please contact Southwest Drinking Water Regional Operations at (360) 236-3030 or via email SWRO.Admin@DOH.WA.GOV.
3. This invoice is issued in accordance with WAC 246-290-990(3)(c)(iii).
4. For persons with disabilities, this document is available on request in other formats. To submit a request, please call 711 Washington Relay Service.
5. If paying by check:

   Make checks payable to Department of Health, Federal ID #91-1444603.

Please return the bottom portion of this invoice with your check.

Invoice Number: 50990
Invoice Amount: $408.00
Owner Number: 004244
WS Name: TUMWATER CITY OF

Invoice Date: 02/01/2023
Invoice Due Date: 03/03/2023
Region: SW
WS ID: 89700

Reference: PROJECT AND PLAN REVIEW FEES

Please remit to:
ACCOUNTS RECEIVABLE
DOH PROJECT AND PLAN REVIEW FEES
PO BOX 1099
OLYMPIA, WA 98507-1099

1DWA10597240100 PP00089700X03032300040800

DOH Staff Name: Candida Granillo-Dodds
Sublog Number: 22-1201
Water System ID: 89700Q

System Name: City of Tumwater
County: Thurston

Fixed Fee for Service

WATER SYSTEM PLANS

			Approved?	
Project Type	Fee 1st Review	Fee 2nd Review	Number Hr 1st Review	Number Hr 2nd Review
Total Water system plans	$0	$0	0	0

SATELLITE MANAGEMENT AGENCY (SMA) PLANS

			Approved?	
Project Type	Fee 1st Review	Fee 2nd Review	Number Hr 1st Review	Number Hr 2nd Review
Total SMA	$0	$0	0	0

PROJECT REPORTS

			Approved?	No
Project Type	Fee 1st Review	Fee 2nd Review	Number Hr 1st Review	Number Hr 2nd Review
Total Project Reports	$0	$0	0	0

CONSTRUCTION DOCUMENTS

			Approved?	No
Project Type	Fee 1st Review	Fee 2nd Review	Number Hr 1st Review	Number Hr 2nd Review
Total Construction documents	$0	$0	0	0

EXISTING SYSTEM APPROVAL

			Approved?	
Project Type	Fee 1st Review	Fee 2nd Review	Number Hr 1st Review	Number Hr 2nd Review
Total of Existing System approval	$0	$0	0	0

GROUP B AND OTHER EVALUATIONS AND APPROVALS

			Approved?	No
Project Type	Fee 1st Review	Fee 2nd Review	Number Hr 1st Review	Number Hr 2nd Review
Total of Other evaluations and approvals	$0	$0	0	0
Total Fixed Fee for Service	**$0**	**$0**	**0**	**0**

Hourly fee for service	Fee	# Hr	System Size	
Corrosion Control Study	$408	4.0	>=500	
Pay This Invoice Amount For This Review	**$408**	**4.0**	**4**	**0**

	Total for All Project Invoices	Total for All Project Hours
Summary	$408	4

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Appendix B.
Analogous Water Systems Corrosion Control Studies

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CITY OF OLYMPIA

THURSTON COUNTY **WASHINGTON**

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McALLISTER WELLFIELD CORROSION CONTROL FACIILITY PROJECT REPORT

G&O #12225.07
JULY 2015

Gray & Osborne, Inc.
CONSULTING ENGINEERS

2102 CARRIAGE DRIVE SW, BUILDING I
OLYMPIA, WASHINGTON 98502
(360) 292-7481

CITY OF OLYMPIA

THURSTON COUNTY WASHINGTON

McALLISTER WELLFIELD CORROSION CONTROL FACILITY PROJECT REPORT

JOSEPH M. PLAHUTA
50105
7/30/15

G&O #12225.07
JULY 2015

Gray & Osborne, Inc.
CONSULTING ENGINEERS

2102 CARRIAGE DRIVE SW, BUILDING I
OLYMPIA, WASHINGTON 98502
(360) 292-7481

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CHAPTER 2 – BACKGROUND INFORMATION

CHAPTER 3 – CORROSION CONTROL ANALYSIS AND DESIGN CRITERIA

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LIST OF FIGURES

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CHAPTER 1

INTRODUCTION

BACKGROUND

The City of Olympia (City) owns and operates a public water system that supplies water to over 59,000 customers located within the City's water service area. The Department of Health (DOH) water system identification number for this system is 63450. The water system is currently supplied with water from the McAllister Wellfield and six groundwater wells.

In 1997, the City drilled wells TW-22 and PW-24 on the McAllister Wellfield site. Test pumping results from these wells showed that this site could support development of wells with excellent water quality that could ultimately replace the McAllister Springs. The City spent the next 15 years working to obtain water rights for the McAllister Wellfield. In 2012, the Department of Ecology issued a water right decision that allows the City to transfer its water rights for McAllister Springs and Abbot Springs to the McAllister Wellfield. As part of this water rights transfer process, the City agreed to provide up to 3.0 MGD of water rights from the wellfield to the Nisqually Tribe.

In 2012, the City drilled an additional well, PW-25, on the McAllister Wellfield site. The City also constructed an extension of the City's 36-inch water transmission main from the McAllister Wellfield site, north to the existing transmission main between McAllister Springs and the Meridian Reservoir Site.

In 2014, the first phase of wellfield development was completed, which included equipping wells TW-22, PW-24, and PW-25, constructing associated treatment facilities for disinfection, and connecting the wells to the transmission main. The City is currently operating the McAllister Wellfield as a complete replacement for the McAllister Springs facility. The facility is currently equipped to produce 10,500 gpm (15 MGD) with an ultimate build-out capacity of 16,000 gpm (23 MGD).

Water produced by the McAllister Wellfield is pumped to two existing 4-million gallon reservoirs collectively referred to as the Meridian Reservoirs. These reservoirs are located approximately 7,000 feet to the northwest of the McAllister Wellfield and feed the City of Olympia's water distribution system at a hydraulic grade of 301 feet MSL. Figure 1-1 shows the relative locations of the McAllister Wellfield, McAllister Springs, and the Meridian Reservoirs.

Water produced by the McAllister Wellfield has a pH of approximately 6.5. The City of Olympia is constructing an aeration tower corrosion control facility to increase the pH of the water produced by the McAllister Wellfield. The facility will initially consist of three aeration tower units to treat the initial total wellfield flow rate of 10,500 gpm. A fourth

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tower unit will be added in the future to treat the ultimate wellfield production capacity of 16,000 gpm.

SCOPE

Gray & Osborne, Inc. was contracted by the City to prepare a project report and complete the engineering design for the McAllister Wellfield Corrosion Control Facility Project Report. This project report includes a description of the following components for this project:

- Background
- Project Need
- Project Funding
- Regulatory Requirements
- Water Quality
- Background Information
- Corrosion Control Analysis and Design Criteria

PROJECT NEED

The City has determined that the pH of the McAllister Wellfield water should be raised to optimize corrosion control in the distribution system. Gray & Osborne completed an evaluation of corrosion control optimization alternatives in 2013. This analysis recommended pH adjustment using aeration by means of an aeration tower to remove dissolved carbon dioxide from the McAllister Wellfield Water.

PROJECT FUNDING

The City will use capital improvement funds to fund the McAllister Wellfield Corrosion Control Facility Project.

REGULATORY REQUIREMENTS

The Washington Administrative Code (WAC) Section 246-290-110 requires the submittal of a project report to the Department of Health for any new water system, water system extension, or improvement not covered by categorical exemption. This Project Report is intended to fulfill the requirements of WAC 246-290-110.

The State Environmental Policy Act (SEPA) requires all governmental agencies to consider environmental impacts of a proposal before making decisions. The City of Olympia has issued a SEPA Determination of Non-Significance for this project which is included in Appendix A.

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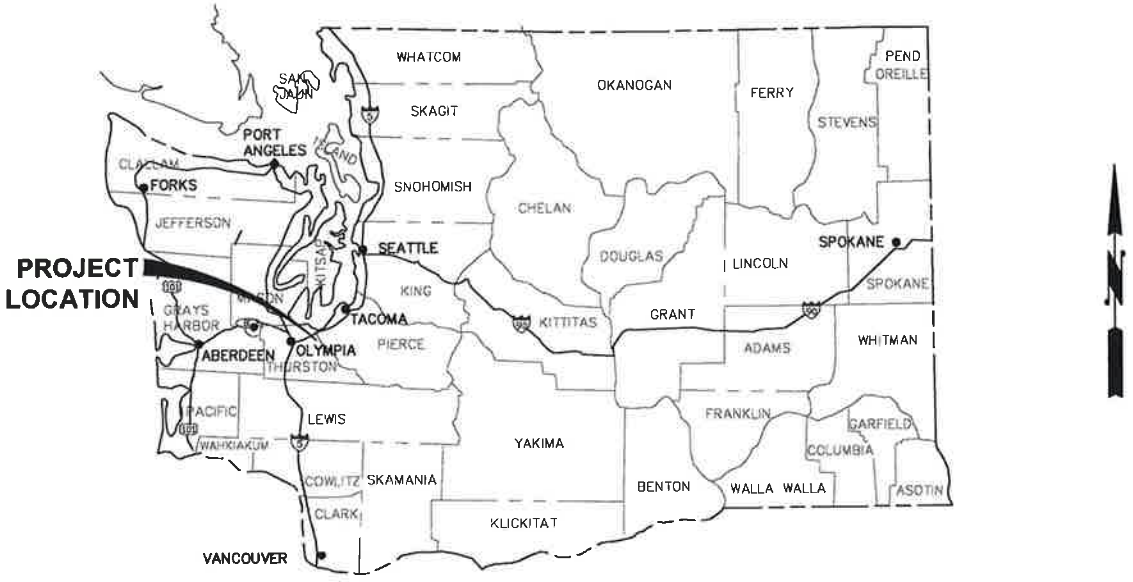
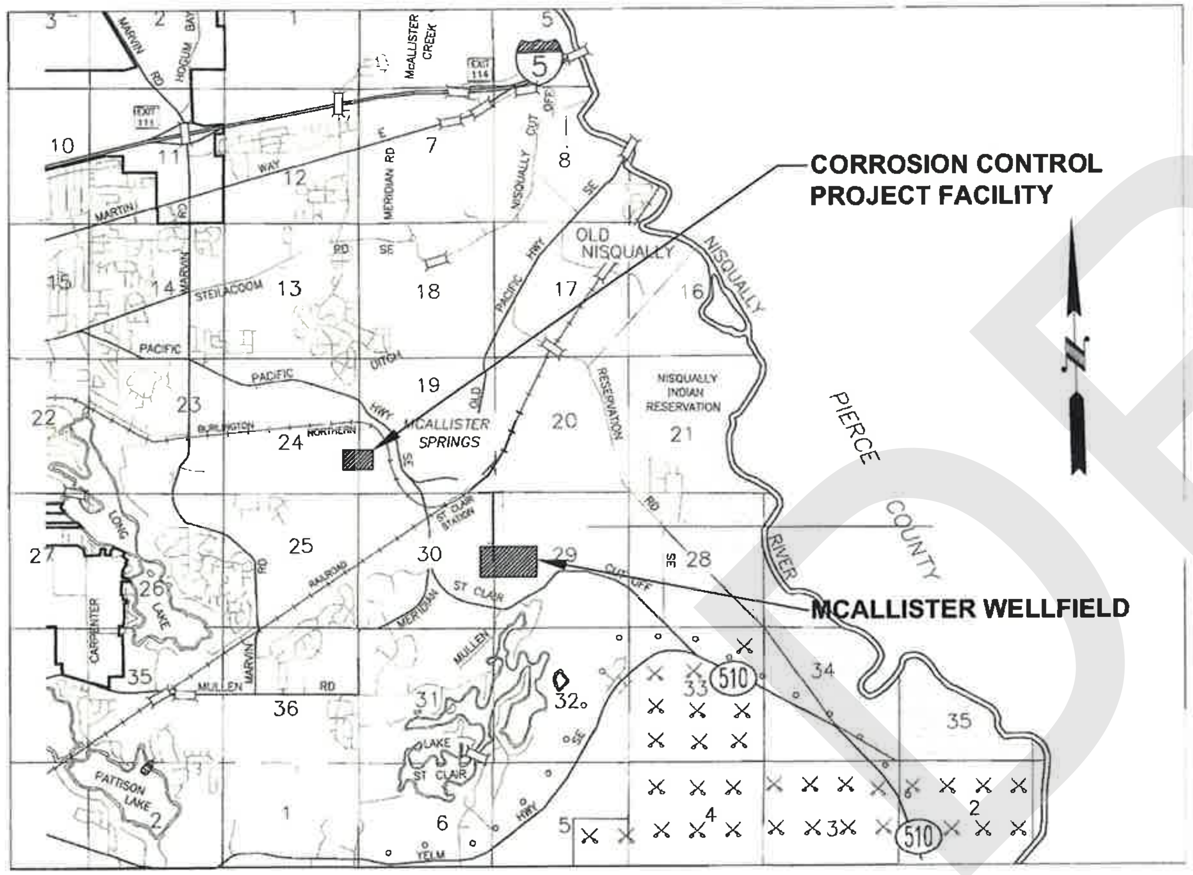


VICINITY MAP
NOT TO SCALE



LOCATION MAP
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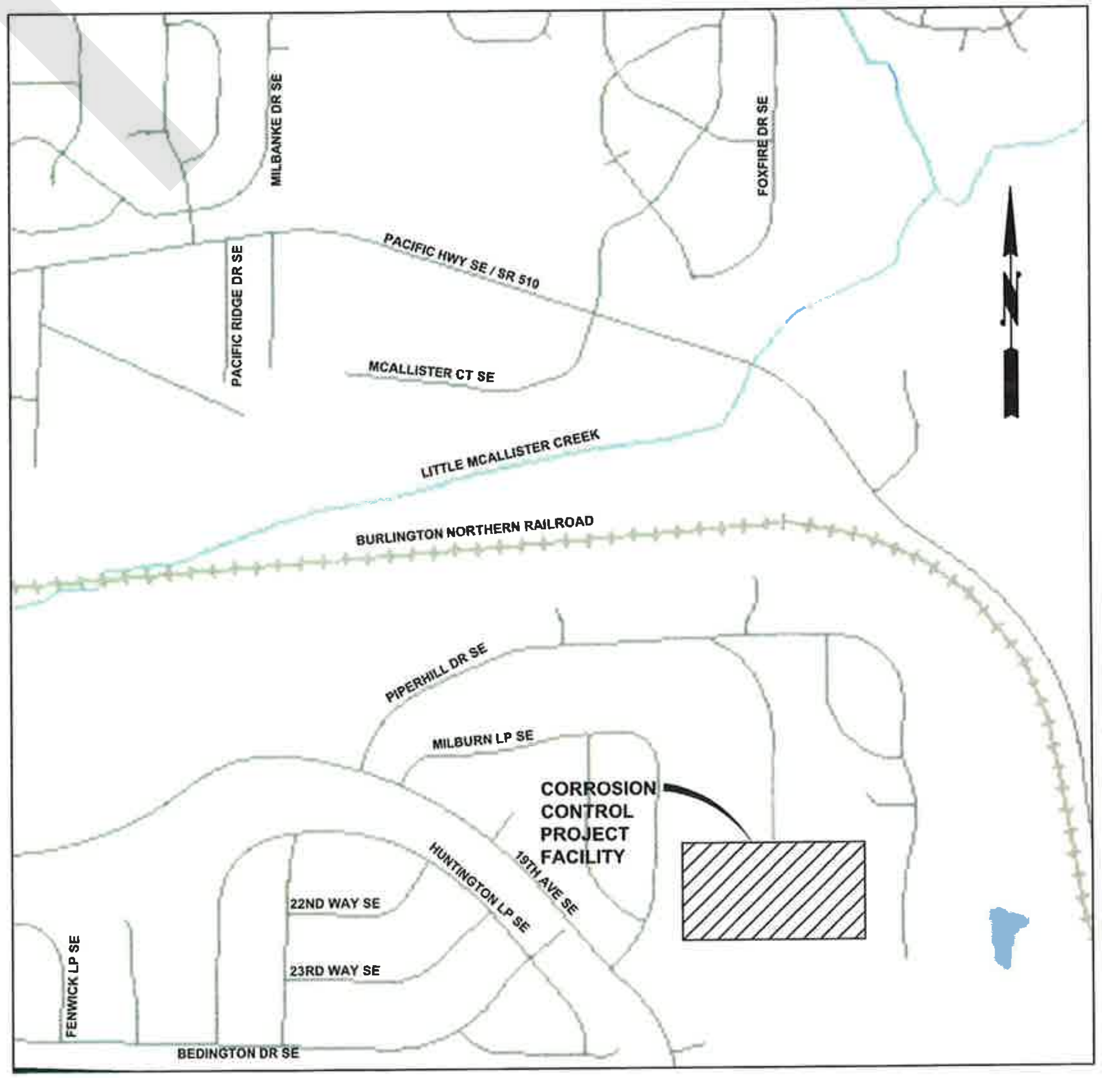

PROJECT MAP
NOT TO SCALE

CITY OF OLYMPIA
MCALLISTER WELLFIELD
CORROSION CONTROL FACILITY PROJECT REPORT
FIGURE 1–1
PROJECT VICINITY MAP

Gray & Osborne, Inc.
CONSULTING ENGINEERS

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M:\Olympia\12225 McAllister Wellfield\12225.07 Corrosion Control Design - CM\FIGURE 1-1.dwg, 5/1/2015 1:45:18 PM, DWG To PDF.pc3

The McAllister Wellfield Corrosion Control Facility project site is located in unincorporated Thurston County. Per the Thurston County Permit Assistance Center, the following County permits are required for the project:

- Department of Health Project Approval
- Thurston County Special Use Permit (already obtained by City)
- Construction Permit (for filling and grading activities)
- Building Permit (for blower building and aeration towers)

Since less than 1 acre will be disturbed by construction activities, the City will not need to obtain coverage from the Department of Ecology under the NPDES Construction Stormwater General Permit.

Since the project will include construction of blowers, the City will need to obtain an air quality discharge permit from the Olympic Region Clean Air Agency.

WATER QUALITY

The two most important water quality parameters of concern for corrosion control are pH and alkalinity. These parameters have been monitored at wells TW-22, PW-24, and PW-25 at various times during the last 20 years. A summary of the most recent existing pH, alkalinity, and temperature data taken at each well is included in Table 1-1.

TABLE 1-1

Summary of pH and Alkalinity Data for Wells TW-22, PW-24, and PW-25

Analyte	Value	Sample Date
Well TW-22		
pH	6.6	September 2012
Alkalinity (mg/L as $CaCO_3$)	54.6	
Well PW-24		
pH	6.6	January 2013
Alkalinity (mg/L as $CaCO_3$)	55	
Well PW-25		
pH	6.5	February 2013
Alkalinity (mg/L as $CaCO_3$)	54	

As can be seen in Table 1-1, recent water quality analysis shows little difference in water quality between Wells TW-22, PW-24, and PW-25 with average pH of 6.6 and alkalinity of 55 mg/L (as $CaCO_3$).

According to *Standard Methods for the Examination of Water and Wastewater* methodology, the calculated dissolved carbon dioxide in the McAllister Wells is approximately 20 mg/L using the average alkalinity and pH values given in Table 1-1.

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A more thorough inventory and evaluation of water quality parameters has been completed as part of the *McAllister Wellfield Corrosion Control Optimization and Treatment Analysis* completed by Gray & Osborne under separate cover in April 2013. The complete report is available in Appendix B.

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CHAPTER 2

BACKGROUND INFORMATION

PREVIOUS REPORTS

The following reports were prepared previously and have been reviewed and referenced in development of this report.

Economic and Engineering Services, McAllister Springs/Meridian Reservoir Corrosion Control Facility Pre-Design Report, 1996

Following the State's adoption of the U.S. Environmental Protection Agency's (EPA's) Lead and Copper Rule in 1995, the City examined corrosion control options for McAllister Springs as a way of reducing copper concentrations within the distribution system.

This report examined four options for increasing spring water pH by removing carbon dioxide including aeration towers, multiple tray aeration, spray nozzle aeration, and diffused air aeration at the Meridian Reservoirs. In addition to considering cost and operational issues, pilot studies were conducted to determine the ability of diffused air and aeration tower aeration to elevate the spring water pH. The studies varied water flow rate, airflow rate, air-to-water ratios, water depth, and liquid loading rate.

The aeration tower pilot study showed fairly similar final pH levels (7.7 to 7.9) for a variety of air-to-water ratios. Since air-to-water ratios greater than five were thought by the study's authors to have no added effect on carbon dioxide removal, the liquid loading rate was the primary factor for determining final pH in the study. Due to the consistent results of the pilot study, the report does not determine a specific pH operating point, stating that other conditions such as power requirements and costs must also be considered.

The diffused air pilot study results were less clear than that for the aeration towers, yet still indicated a final pH of over 7.5 would be achieved. For diffused aeration, the air-to-water ratio, liquid detention time, and diffuser depth all contribute significantly to results. The pilot study accounts for these factors; however, its ability to accurately predict pH increase in actual implementation can only be inferred based on the relative accuracy of the pilot study.

Based on pilot studies and data available from other systems, the only methods considered capable of reliably elevating the pH from McAllister Springs were aeration towers and diffused air. The predesign report recommended diffused air over aeration towers due to cost and potential challenges maintaining CT since chlorine is more effective at lower pH values. Treatment was never installed at the springs, primarily

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because lead and copper levels were reduced after installing treatment at other sources, and because the City had already initiated wellfield project planning.

HDR, Technical Memorandum/Wellfield Transition Water Quality Assessment, March 2008

As part of the City's 2009 Water System Plan, the City assessed the potential impact of changing from McAllister Springs to the McAllister Wellfield in a technical memorandum. The memorandum provided a system overview, comparison of water quality between the McAllister Wellfield and McAllister Springs and the other City sources, and a discussion of water quality. The report recommended that the wellfield water pH be raised above 7.5 to provide corrosion control and minimize scale dissolution.

Gray & Osborne, Corrosion Control Optimization and Alternatives Analysis, April 2013.

Concurrent with design of the McAllister Wellfield, the City assessed the optimum distribution system pH for corrosion control. This analysis included an extensive examination of existing source water chemistry, distribution system water quality, water quality blending issues, and scale chemistry. The City's hydraulic model was used in the blending analysis to help predict water quality at various locations throughout the distribution system.

The report also evaluated corrosion control alternatives for optimizing pH in the distribution system. The report agreed with the earlier conclusions of the HDR technical memorandum, confirming that an adjusted source water pH of 7.5 would optimize corrosion control. The report evaluated aeration tower, diffused bubble aeration, spray nozzle aeration, and caustic addition as potential corrosion control measures. Aeration tower and diffused bubble aeration were both able to adjust the pH above the target level of 7.5. Ultimately, aeration tower aeration was recommended since it offers a lower lifecycle cost than diffused bubble aeration.

AERATION THEORY

Aeration can be used as a corrosion control technology because it removes dissolved carbon dioxide from the water. Dissolved carbon dioxide reacts with water to form carbonic acid. Removal of carbon dioxide removes the carbonic acid and, therefore, increases the pH. The aeration process can remove dissolved carbon dioxide from the water until it equilibrates with atmospheric levels of carbon dioxide. The pH of the water at atmospheric equilibrium is dependent upon the alkalinity and temperature of the water. Higher alkalinity or warmer water will have a higher equilibrium pH.

Figure 2-1 shows the pH versus dissolved carbon dioxide relationship for the water from the McAllister Wellfield based upon an average alkalinity of 55 mg/l as $CaCO_3$. As mentioned previously, the raw water dissolved carbon dioxide concentration for a pH of

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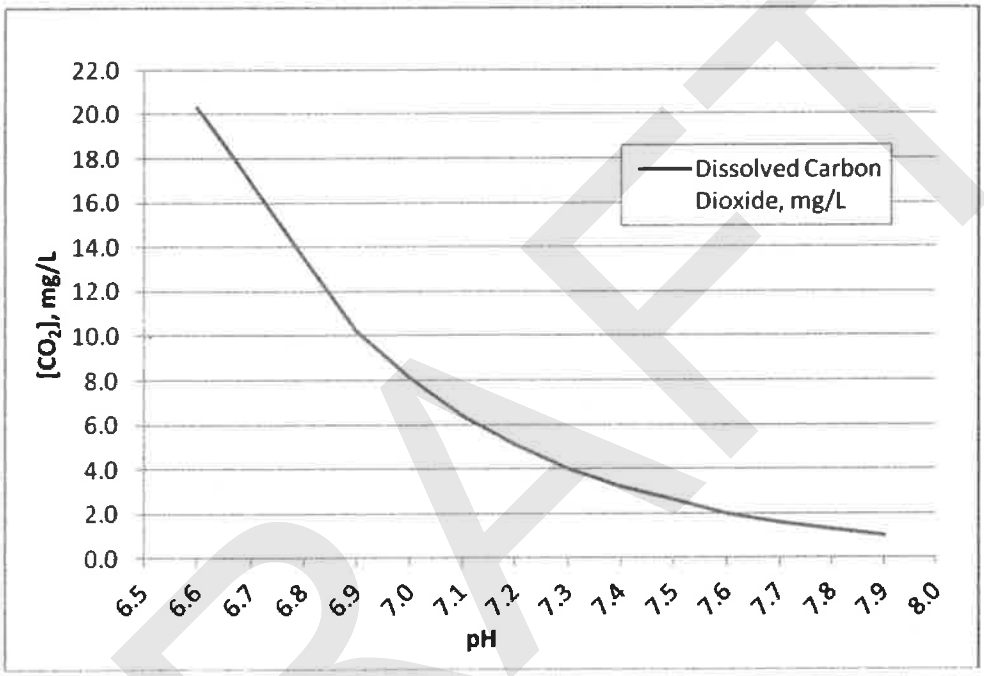
6.6 is approximately 20 mg/l. Assuming a water temperature of 10 °C and an atmospheric carbon dioxide concentration of 395 ppm, the equilibrium dissolved carbon dioxide concentration is 0.9 mg/l, corresponding to a pH of 7.9. This represents the highest pH achievable with aeration at the McAllister Wellfield site.

Figure 2-1

Dissolved Carbon Dioxide with pH



OTHER ANALOGOUS INSTALLATIONS

Many pilot and full scale installations have demonstrated carbon dioxide removal by aeration. Information on some of these installations is included in Table 2-1.

The data in Table 2-1 indicate that the aeration facilities listed are approximately 94-99% efficient in removing carbon dioxide to an atmospheric equilibrium. It is expected that the McAllister Wellfield facility will have similar removal efficiency. If an efficiency of 95% is assumed for the McAllister Wellfield site, a pH of 7.9 is expected from aeration treatment. This calculation is based upon the average pH and alkalinity values given in Table 1-1 and the dissolved carbon dioxide to pH relationship given in Figure 2-1.

During the City of Vancouver Water Station No. 14 Corrosion Control Pilot Study, performed by Gray & Osborne in 1996, the effect of three different design variables, listed below, on carbon dioxide removal was investigated. The variables are listed below by relative importance.

- Aeration packing height

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- Hydraulic loading
- Air to water ratio

The pilot study data indicated that the most influential design parameter was tower packing height. Hydraulic loading was influential to a lesser effect. Increases in air to water ratio had a slight effect on carbon dioxide removal up to a ratio of 50:1. Above this value there was no additional carbon dioxide removal.

TABLE 2-1

Summary of Aeration Installation pH Adjustment Performance

Installation Location	Water Quality Parameter	Value
City of Vancouver (1) Water Station No. 1	Raw Water pH Raw Water Alkalinity Tower Packing Aerated pH Efficiency (6)	7.4 97 mg/l as $CaCO_3$ 20 feet 8.1 93%
City of Vancouver (2) Water Station No. 4	Raw Water pH Raw Water Alkalinity Tower Packing Aerated pH Efficiency (6)	6.9 75 mg/l as $CaCO_3$ 20 feet 7.9 96%
City of Vancouver (3) Water Station No. 14 Pilot Study	Raw Water pH Raw Water Alkalinity Tower Packing Aerated pH Efficiency (6)	6.5 113 mg/l as $CaCO_3$ 15 feet 7.9 98%
Fort Lewis (3) Aeration Pilot Study	Raw Water pH Raw Water Alkalinity Tower Packing Aerated pH Efficiency (6)	6.6 48 mg/l as $CaCO_3$ 15 feet 7.9 99%
City of Olympia (4) Shana Park	Raw Water pH Production Rate Aerated pH Efficiency (6)	5.8 1,100 gpm 7.2 - 7.4 97-98%
City of Olympia (5) Allison Springs	Raw Water pH Production Rate Aerated pH	6.1-6.3 1,900 gpm maximum 7.2 - 7.4

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Installation Location	Water Quality Parameter	Value
	Efficiency (6)	90-96%

(1) Hydraulic Loading: 25 gpm/ft^2; Air:Water Ratio: 18:1
(2) Hydraulic Loading: 26 gpm/ft^2; Air:Water Ratio: 10:1
(3) Hydraulic Loading: 20 gpm/ft^2; Air:Water Ratio: 50:1
(4) Hydraulic Loading: 22 gpm/ft^2; Air:Water Ratio: 30:1
(5) Hydraulic Loading: 30 gpm/ft^2; Air:Water Ratio: 25:1
(6) Efficiencies shown are percentages of removal to atmospheric equilibrium, and have been calculated by Gray & Osborne from available pH and alkalinity data.

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CHAPTER 3

CORROSION CONTROL ANALYSIS AND DESIGN CRITERIA

INTRODUCTION

This chapter evaluates alternatives and summarizes design choices and criteria for the McAllister Wellfield Corrosion Control Facility. The following issues are addressed in this chapter.

- Number and Size of Aeration Towers
- Aeration Tower Treatment Process
- Aeration Tower Material
- System Hydraulics
- Aeration Tower Construction
- Blower Sizing
- Aeration Tower Flow Controls
- Blower Enclosure
- Cleaning System
- Electrical Supply and Standby Power
- Instrumentation, Telemetry, and Controls
- Project Construction Cost

A number of evaluations were completed during the design process to assist the City with evaluating design alternatives. These evaluations are summarized under the headings below.

NUMBER AND SIZE OF AERATION TOWERS

The facility will initially consist of three aeration towers for a treatment capacity of 15 MGD. At a later date, a fourth tower will be constructed to provide a total treatment capacity of 23 MGD.

AERATION TOWER TREATMENT PROCESS

Packed tower aeration will be used to treat raw water from the McAllister Wellfield. Raw water will be pumped from the wells to the top of the Aeration Tower. A distribution header or array of nozzles will control the distribution of the water over the cross sectional area of the tower. The water droplets will then fall onto a bed filled with plastic aeration packing. The packing allows a high surface area to volume ratio, and supports the propagation of small droplets falling through the entire height of the tower to

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facilitate efficient gas transfer. The water droplets will continue to fall past the packing and will be collected in a sump or clearwell below the Aeration Tower.

In addition to the aeration packing and distribution apparatus, the towers will contain packing supports, manways, and a demister. The packing support will allow the flow of air and water while supporting the packing material above it. Inspection ports and manways will be constructed in the tower shell to facilitate inspection as well as the installation of packing material. A demister will be installed above the other tower appurtenances to remove droplets from the air stream leaving the aeration tower.

The design parameters for the aeration towers are shown in Table 3-1 and Figure 3-1 shows the layout of the aeration towers. The towers have been designed to accommodate the expected range of flows from the McAllister Wellfield.

TABLE 3-1

Aeration Tower Design Criteria

Parameter	Value
Target pH	7.5
Air to Water Ratio	10:1
Air Requirement	
Current Peak Production Capacity (15 MGD)	16,200 cfm
Future Peak Production Capacity (23 MGD)	21,600 cfm
Packed Towers	
Number, Current Capacity	3
Number, Future Capacity	4
Dimensions	14 foot diameter, 41 feet tall
Packing Height	15 feet
Design Flow Rate	4,000 gpm
Surface Loading Rate (3 towers)	26 gpm/sf
Blowers	
Number, Current Capacity	3
Number, Future Capacity	4
Flow per Blower (cfm)	6,000 cfm
Pressure (inches of water)	5.2 inches
Horsepower per Blower	7.5 hp

(1) Projected average day demand in taken from Table 9.2 of the City of Olympia 2009-2014 Water System Plan and assumes that all demand would be met by the McAllister Wellfield.

As shown in Table 3-1, three aeration towers will be required initially with a fourth to be installed concurrent with expansion of the wellfield to a capacity of 23 MGD. Each tower will need to be 14 feet in diameter and 41 feet in height with a packing depth of 15 feet. Each tower will be provided with a dedicated blower to introduce air countercurrent to water flow at the base of the packing material.

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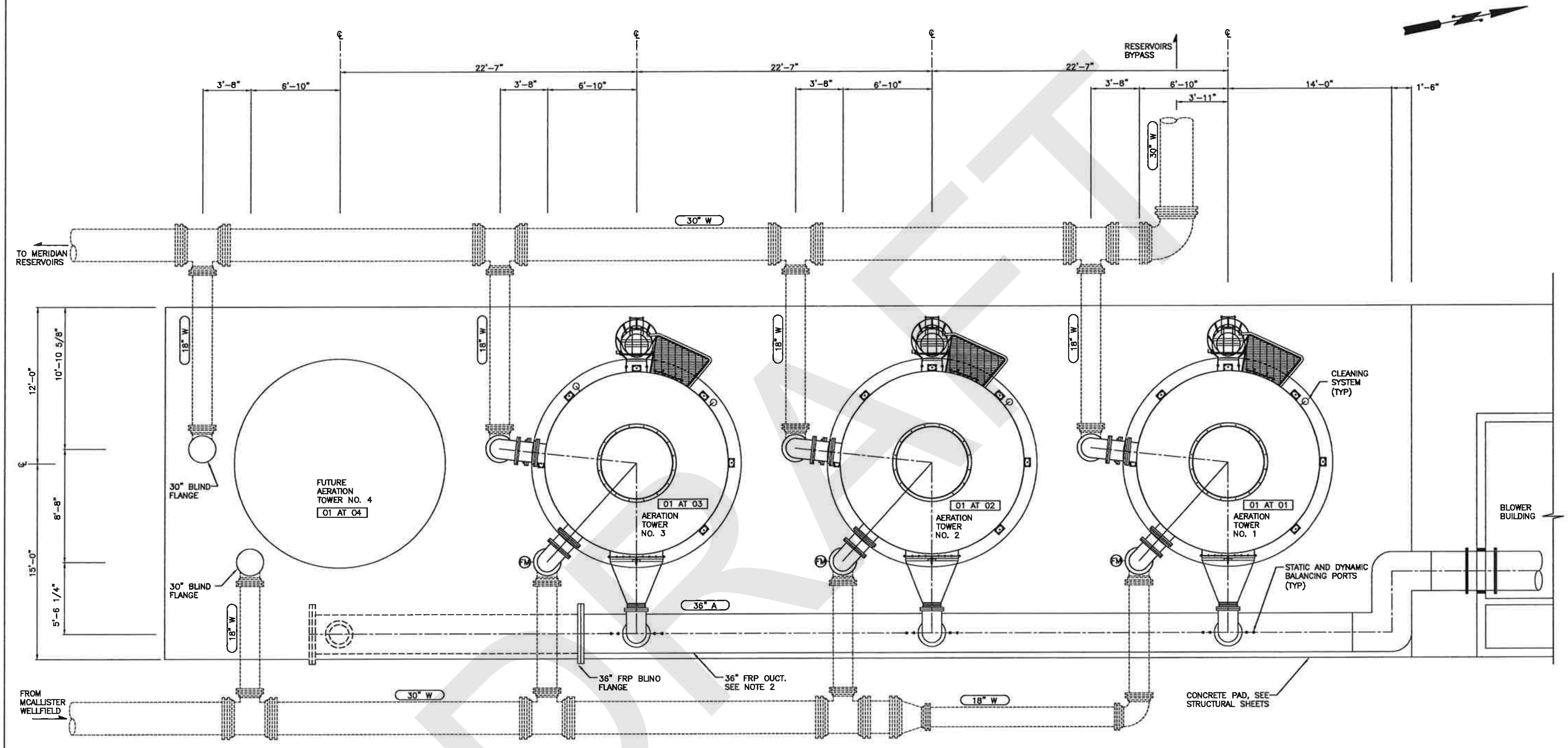

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NOTES:

1. INSTRUMENTATION CONNECTIONS ARE NOT SHOWN FOR CLARITY.
2. INSTALL DUCTWORK TO PROVIDE 0.5% SLOPE TO THE SOUTH. INSTALL DRAIN WITH A ½" BALL VALVE AT SOUTHERN END OF DUCT.

AERATION TOWER MECHANICAL PLAN

SCALE: 1/4"=1'-0"

CITY OF OLYMPIA
MCALLISTER WELLFIELD
CORROSION CONTROL FACILITY PROJECT REPORT
FIGURE 3-1
AERATION TOWER LAYOUT
Gray & Osborne, Inc.
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AERATION TOWER MATERIAL

Packed tower aerators are typically constructed from aluminum, stainless steel, or fiberglass reinforced plastic (FRP). Each of these materials has intrinsic advantages and disadvantages, and are evaluated below.

Aluminum

Aluminum is frequently used for the construction of packed tower aerators. Aluminum has good structural properties and is generally resistant to corrosion in a potable water environment. However, unlike stainless steel or FRP, aluminum is not inherently resistant to corrosion but instead relies upon a thin oxide layer to protect the base metal from corrosion. Like stainless steel, aluminum is somewhat malleable and is therefore resistant to fatigue cracking from thermal expansion and contraction. Aluminum is also immune to photodegradation. In terms of cost, aluminum is competitive with FRP, and considerably less expensive than stainless steel.

Stainless Steel

Stainless steel is a less commonly utilized material for packed tower aerators due to its high cost. However, due to its corrosion resistance and strength, it is more durable than either aluminum or FRP. Like aluminum, stainless steel is highly resistant to fatigue cracking and does not photo-degrade. However, stainless steel is also very expensive so its use is typically limited to applications handing hot and/or corrosive liquids.

Fiberglass Reinforced Plastic (FRP)

FRP consists of glass strands imbedded in a matrix of resin material (typically epoxy, or vinyl ester). FRP is a commonly used and economical material for packed tower aerators. This is particularly true in the northwest where the mild climate lessens concerns relating to thermal stress. In general, FRP is very durable and highly corrosion resistant; however, it can be subject to degradation from sunlight and fatigue cracking from thermal expansion and contraction. Furthermore, the resins in FRP tend to lose plasticity with time, making the material more brittle with age. Resin degradation can be mitigated by application of a protective coating to the exterior of the tower.

Since western Washington experiences relatively low thermal extremes, FRP is the preferred material due to its excellent corrosion resistance and relatively low capital costs. Therefore, the aeration towers will be constructed of FRP.

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SYSTEM HYDRAULICS

Since the overflow of the existing reservoirs is located at an elevation of 301 feet, the outlet water surface elevation of the corrosion control towers will need to be located at an elevation equal to 301 feet plus the headloss in the piping between the towers and the reservoir at 23 MGD. Assuming 18-inch ductile iron pipe to each tower, and 30-inch ductile iron header pipe, the headloss between the towers and the reservoir at 23 MGD is approximately 6.3 feet; therefore, the aeration tower outlet water level will be at an elevation of approximately 307.5 feet. Since the existing ground surface is at an elevation of approximately 293 feet, the aeration tower outlet will need to be elevated approximately 14.5 feet above ground level.

AERATION TOWER CONSTRUCTION

Four different alternatives were evaluated for elevating the towers in order to allow treated water to flow from the towers to the reservoir.

1. Purchase the packed towers with an integral clearwell.
2. Install the packed towers on a cast-in-place concrete clearwell.
3. Construct the packed towers on a concrete mechanical building.
4. Construct the towers on a slab-on-grade, cast on fill material placed behind a retaining wall.

Each of these alternatives is discussed further below. Alternatives 1, 2, and 3 do not require significant modification of the grades at the reservoir site since a new structure is used to provide the necessary elevation. Alternative 4 would require substantial earthwork and construction of a retaining wall in order to provide the necessary base elevation for the aeration towers. A cost summary for each of the alternatives is provided in Table 3-2.

Alternative 1 – Integral Clearwell

This alternative would provide a clearwell integrated into the base of the packed tower aerator to elevate the aeration towers. The existing ground surface elevation at the proposed location of the aeration towers would be filled to an elevation of approximately 295 feet. This necessitates that the clear well be approximately 16 feet high in order to provide a water surface elevation of 307.5 feet and 3.5 feet of headspace. Therefore, the aeration tower furnished by the manufacturer would be approximately 41 feet tall. The entire aeration tower and sump assembly would be secured to a concrete slab with an elevation of 295 feet.

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The advantage of this alternative is that the aeration tower and sump can be manufactured together, minimizing the amount of work needing to be performed onsite. However, assuming that the blowers are located at ground level, additional ducting would be required to reach the air inlet at the base of the aeration tower.

The estimated cost for constructing this alternative is $3,350,000 to $3,500,000 depending upon the enclosure provided for the blowers.

Alternative 2 – Concrete Clearwell

This alternative would provide a cast-in-place concrete clearwell to elevate the base of the aeration towers. The existing ground surface elevation at the proposed location of the aeration towers is approximately 295 feet. This necessitates that the clear well be approximately 14.5 feet high in order to provide a water surface elevation of 307.5 feet, 1 foot of freeboard, and 1 foot of top slab thickness. Therefore, a 14.5 foot high concrete clearwell would be constructed with a top elevation of 309.5 feet. The aeration towers would be anchored to the top of the clearwell and the connection between the tower and the clearwell engineered to resist overturning. The total height of the aeration tower assembly supplied by the manufacturer would be approximately 25 feet.

The estimated cost for constructing this alternative is $3,620,000.

Alternative 3 – Concrete Mechanical Building

This alternative would provide a cast-in-place concrete mechanical building to elevate the base of the aeration towers. The existing ground surface elevation at the proposed location of the aeration towers is approximately 295 feet. This necessitates that the concrete building be approximately 12.5 feet high in order to provide a tower base elevation of 307.5 feet. Therefore, a 10 foot high concrete building would be constructed with a top elevation of 307.5 feet. The aeration tower would be anchored to the top of the building and the connection between the tower and the building engineered to resist overturning. The total height of the aeration tower assembly supplied by the manufacturer would be approximately 25 feet.

Piping would exit the base of each tower and feed into a common header located in the space within the concrete structure. The blowers would be located in the concrete structure for weather protection and to reduce noise. This alternative is similar to the concrete clearwell alternative. Waterstops would not be required, but heating, ventilation, and air conditioning (HVAC) provisions would need to be made and floor drains would need to be installed in the building.

The estimated cost for constructing this alternative is $3,730,000.

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Alternative 4 – Grading Modifications

This alternative would provide the necessary tower base elevation thorough filling, grading, and construction of a retaining wall. The grade at the proposed location of the aeration towers would be raised approximately 10 feet to an elevation of 304 feet. Since the area where filling will take place is located on a slope, a retaining wall approximately 12-foot tall would need to be constructed along the east side of the aeration towers to provide a level foundation for the aeration towers. A concrete foundation slab would then be poured to a top-of-slab elevation of 307.5 feet. The aeration tower assembly would then be anchored to this slab and piping made up through the slab to the base of the aeration tower.

The estimated cost for constructing this alternative is $3,620,000.

TABLE 3-2

Alternative Aeration Tower Construction Costs Summary

Alternative	Description	Cost
1	Integral Clearwell	$3,350,000 to $3,500,000
2	Cast in-place Concrete Clearwell	$3,620,000
3	Cast in-place Concrete Mechanical Room	$3,730,000
4	Fill Pad with Retaining Wall	$3,620,000

Alternative No. 1 is the preferred alternative since it has the lowest capital cost.

BLOWER SIZING

As shown in Table 3-1, at an air to water ratio of 10:1, approximately 16,200 cfm of air is necessary to treat the initial flow rate of 15 MGD. 21,600 cfm of air will be required to treat the buildout flow rate of 23 MGD. To provide the required air flow (1) separate blowers could be provided for each tower or (2) one large variable speed blower could be provided.

Separate Blowers for Each Tower

If separate blowers are provided for each tower, each blower would need to be able to provide approximately 5,400 scfm. Weather protection would be provided by constructing the blowers from fiberglass reinforced plastic (FRP) or placing the blowers in a weatherproof enclosure or building. With this arrangement, each blower can be directly ducted to it respective tower or the blowers can share a common discharge manifold.

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Singular Blower Serving All Towers

If a singular blower were to be provided, it would need to be able to provide variable airflow from 4,650 cfm to 21,350 cfm. Centrifugal blowers are typically used in packed tower applications due to their greater efficiency and lower capital cost. However, centrifugal blowers must operate in a narrow speed window in order to provide rated airflow and pressure. In order to provide the required 4:1 turndown ratio, a positive displacement blower would be required. A positive displacement blower would likely have a greater capital cost, would have significantly higher operation and maintenance costs, and would be louder.

Since use of a singular blower would preclude the use of more efficient centrifugal blowers, separate constant-speed blowers will be provided for each of the Aeration Towers.

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AERATION TOWER FLOW CONTROLS

The McAllister Wellfield has the ability to provide flow ranging from 1,500 gpm to 10,500 gpm initially and from 1,500 gpm to 16,000 gpm at buildout. The corrosion control facility must be designed to allocate this range of flow between the aeration towers. Three schemes for allocation of flow between the aeration towers were evaluated:

Alternative 1:	Uniform distribution of flow between the aeration towers.
Alternative 2:	Allocation of flow depending upon well operational permutation.
Alternative 3:	Operation of blowers depending upon flow through the aeration towers.

Alternative 1: Uniform Distribution of Flow between the Aeration Towers

With this alternative, water would be distributed evenly amongst the aeration towers regardless of which wells are operating. All blowers would operate regardless of the water flow rate to the corrosion control facility. The advantage of this alternative is simplified operation since no automated valving is required on the inlet to the packed towers. The blowers would be operated according to the amount of flow produced by the wellfield in order to provide a minimum air to water ratio of 10:1.

Alternative 2: Allocation of Flow Depending Upon Well Operational Permutation

With this alternative, water distribution to each packed tower will be dependent upon which wells are operating. In order not to exceed the hydraulic capacity of any of the towers, a motorized valve would be provided on the inlet pipe to each tower. The motorized valves would be opened to allow flow through a particular aeration tower. Flow would be allocated to each tower based on well operational status as shown in Table 3-3. The particular towers that are placed into operation for a given well operational permutation would be adjustable through the system PLC.

Whenever a well is called to run, the appropriate control valves would open or close in order to allow flow through the towers in accordance with the schedule shown in Table 3-3. When the control valve to a particular tower is open, the corresponding blower would turn on to provide countercurrent airflow through the tower. The additional cost to equip the inlet butterfly valves with motorized actuators and to interface with the system PLC is estimated at $55,000.

TABLE 3-3

Water Distribution Control Valve Positions for Different Operational Conditions

Well Operational Status	Tower No. 1 Control Valve	Tower No. 2 Control Valve	Tower No. 3 Control Valve	Tower No. 4 Control Valve(1)(2)
PW-24	Open	Closed	Closed	Closed
TW-22	Closed	Open	Closed	Closed
PW-25	Open	Close	Open	Closed
PW-24 and TW-22	Open	Open	Closed	Closed
PW-24 and PW-25	Open	Open	Open	Closed
TW-22 and PW-25	Closed	Open	Open	Closed
PW-22, PW-24, and PW-25	Open	Open	Open	Closed
PW-22, PW-24, PW-25 and PW-26	Open	Open	Open	Open

(1) The control valve for Tower No. 4 will remain closed until PW-26 and Tower No. 4 are constructed.

(2) For the sake of brevity, only one scenario is displayed with PW-26 operating. The scenario displayed is for all McAllister Wells running and corresponds to a combined flow rate of 16,000 gpm (23 MGD).

Table 3-5 provides a comparison of the average annual operating cost associated with operating the aeration towers with, and without flow allocation.

Alternative 3: Operation of Blowers Depending Upon Flow through the Aeration Towers

With this alternative, the blowers will be connected to a common FRP manifold serving all of the aeration towers. Blowers will turn on according to which wells are operating such that a minimum air to water ratio of 10 is maintained. It is estimated that it will cost an additional $31,000 to construct an FRP manifold to serve the aeration towers. Table 3-4 shows which blowers would run for each possible well operational permutation.

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TABLE 3-4

Blower Status for Different Operational Conditions

Well Operational Status	Blower No. 1 Status	Blower No. 2 Status	Blower No. 3 Status	Blower No. 4 Status(1)(2)
PW-24	ON	OFF	OFF	OFF
TW-22	OFF	ON	OFF	OFF
PW-25	OFF	ON	ON	OFF
PW-24 and TW-22	ON	ON	OFF	OFF
PW-24 and PW-25	ON	ON	ON	OFF
TW-22 and PW-25	ON	OFF	ON	OFF
PW-22, PW-24, and PW-25	ON	ON	ON	OFF
PW-22, PW-24, PW-25 and PW-26	ON	ON	ON	ON

(1) Blower No. 4 will not be installed until PW-26 and Tower No. 4 are constructed.

(2) For the sake of brevity, only one scenario is displayed with PW-26 operating. The scenario displayed is for all McAllister Wells running and corresponds to a combined flow rate of 16,000 gpm (23 MGD).

Table 3-5 provides a comparison of the annual energy cost associated with each of the three flow control alternatives described previously.

TABLE 3-5

Annual Energy Cost Comparison

Scenario	Average McAllister Springs Production (2009-2011)	Projected 2014 Average Day Demand	Projected 2028 Average Day Demand
Average Daily Flow (MGD)	7.3	9.0	10.9
Annual Energy Cost of Alternative 1	$13,000	$16,000	$19,400
Annual Energy Cost of Alternative 2 or Alternative 3	$10,000	$12,300	$14,900
Annual Cost Savings of Alternative 2 or Alternative 3	$3,000	$3,700	$4,500
Payback Period for Alternative 2(2)	18.3	14.9	12.2
Payback Period for Alternative 3(3)	10.3	8.4	6.9

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(1) Annual energy costs for 2014 and 2028 average day demands have been determined by flow scaling the computed annual energy cost determined from existing McAllister Springs production records.
(2) Based on a capital cost of $55,000 to provide control valves for flow allocation.
(3) Based on a capital cost of $31,000 to construct an FRP Blower Header.

Both Alternative 2 and Alternative 3 provide operators with greater operational flexibility. Both of these alternatives also provide identical cost savings relative to Alternative 1. Since the capital cost associated with Alternative 3 is less than the capital cost associated with Alternative 2, a blower header will be installed to distribute air to each tower.

BLOWER ENCLOSURE

The blower units can either be installed outside, adjacent to the packed tower that they serve or in a building constructed adjacent to the packed tower. Installation of the blowers outside would require that they be constructed of FRP or another corrosion resistant material. The primary advantage of placing the blowers inside of a building would be to provide noise reduction and to provide a dry and heated environment for the blowers to be serviced. However, construction of a building would result in significant additional expense. In order to provide adequate space for the four blowers required at buildout capacity, the building would need to be approximately 500 square feet in area and special provisions would need to be made for intake and exhaust ducting. The estimated additional cost (relative to installing the blowers outside) to construct a building for the blowers is $125,000. Furthermore, heating and ventilation would need to be provided for the building, increasing operational costs.

Installing the blowers outside, adjacent to the towers would contribute to increased noise levels at the site. The blowers produce noise at an intensity of 80 decibels (measured at 5 feet from the blower). Chapter 173-60 of the Washington Administrative Code (WAC) sets limits on environmental noise levels. This section of code limits the sound intensity (measured at the property line) in residential areas to 57 decibels during the daytime and 47 decibels during nighttime hours. The proposed location of the blowers will be approximately 200 feet from the nearest property line. Based on attenuation at the inverse square of distance, sound intensity at the nearest property line is estimated to be approximately 48 decibels, an intensity equivalent to the typical background noise in a residential area at night.

Placing the blowers in a building does provide additional attenuation and improves serviceability. Therefore, the blowers and related mechanical equipment, electrical equipment, and instrumentation will be placed inside a concrete masonry building. The buildings will be constructed with concrete strip footings and a concrete floor slab. The building will be provided with wood trusses and a metal roof. The building will also be provided with a heater, exhaust fan, and thermostat to control the temperature in the building. The building will be constructed to meet the requirements of the 2012 International Building Code and current Energy Code. See Figure 3-2 for blower building layout.

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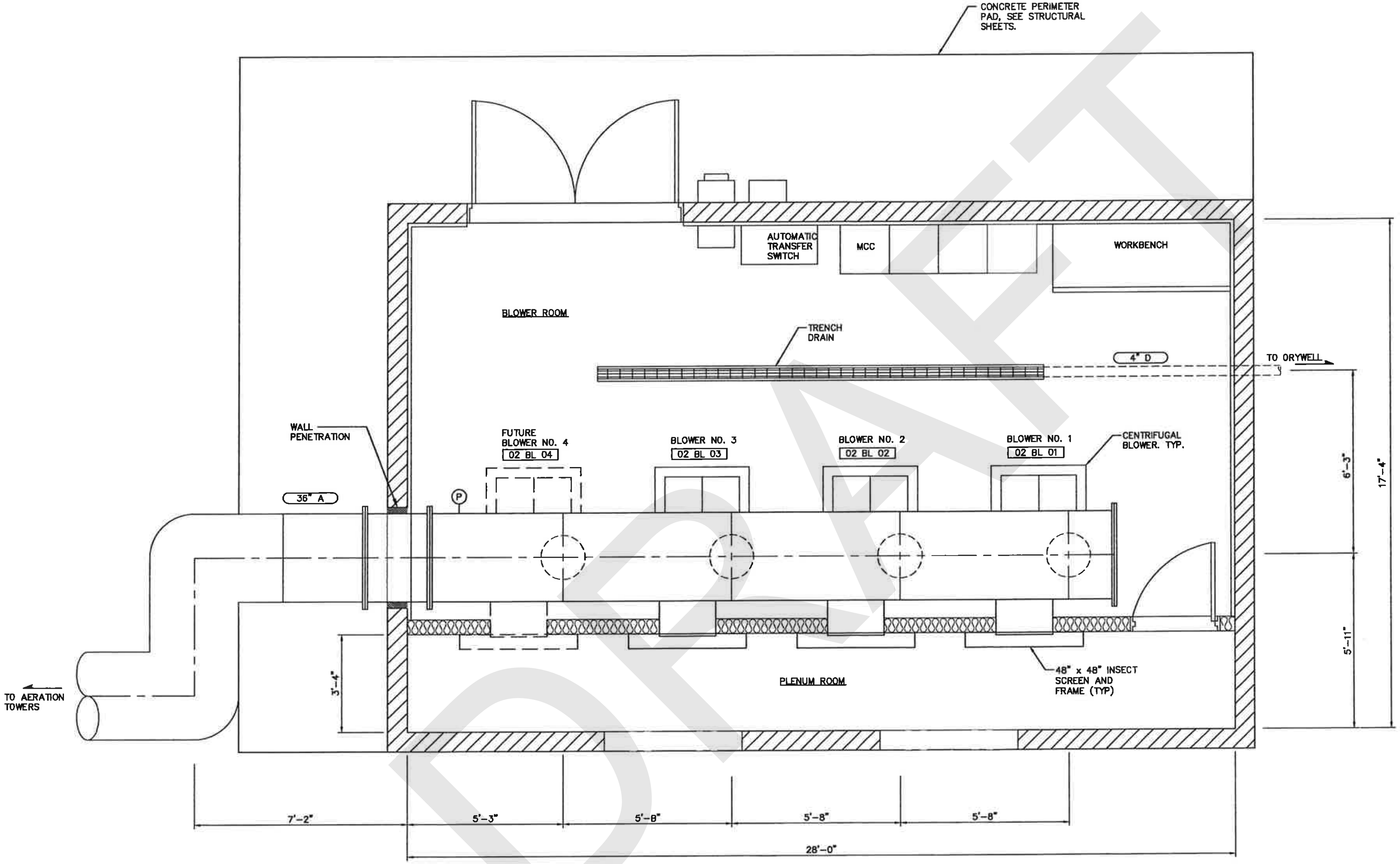
SCALE: 1/2"=1'-0"

NOTES:
1. NOT ALL PIPE SUPPORTS HAVE BEEN SHOWN FOR CLARITY. THE CONTRACTOR SHALL SUPPORT ALL PIPE AS REQUIRED IN SECTION 15066 OF THE SPECIFICATIONS.



BLOWER BUILDING MECHANICAL PLAN

SCALE: 1/2"=1'-0"

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CITY OF OLYMPIA
MCALLISTER WELLFIELD
CORROSION CONTROL FACILITY PROJECT REPORT
FIGURE 3-2
BLOWER BUILDING LAYOUT

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CLEANING SYSTEM

Integral to each aeration tower, a cleaning system will be installed. The cleaning system will be comprised of piping and a spray header to recirculate cleaning solution through the tower packing. Since the McAllister Wellfield produces good quality water, it is not anticipated that cleaning will be required often. Therefore, a permanent pumping system is not provided. When needed, a portable pump will be brought in and connected to piping on the tower unit. The cleaning system can be used periodically to prevent bacterial growth or reduce mineral deposits.

The aeration towers will be removed from service for cleaning by adjusting the controls and closing the inlet and outlet valves. The clearwell level will be lowered until approximately 1,000-2,000 gallons remain in the tower sump. A portable pump will then be brought in; its suction will be connected to the tower sump and its discharge will be connected to a dedicated spray header located above the packing. A cleaning chemical will be added to the tower sump and the pump will recirculate the cleaning solution through the packing.

The system will allow flexibility in the cleaning solution used depending on the situation. Sodium hypochlorite can be fed for biological growths while acid solutions can be used for mineral deposits. At the completion of the cleaning procedure, if necessary, the solution remaining in the clearwell can be neutralized before being hauled to waste. Since, there will be no wastewater disposal facilities located on the project site, cleaning solution in the clearwell would likely need to be hauled offsite by truck for disposal.

It is not expected that mineral deposits will be an issue given the high raw water quality. Furthermore, the fact that the water is chlorinated prior to entering the towers should limit the potential for biological growth. However, installation of the necessary chemical cleaning equipment will allow the City the ability to clean the packing media should the need arise.

Once chemical cleaning is complete, the inlet flow can be resumed and the tower and clearwell rinsed. After disposal of the rinse water, the facility can be placed back into operation.

ELECTRICAL SUPPLY AND STANDBY POWER

112.5 kVA 480V three-phase power is currently available at the Meridian Reservoir Site. The existing transformer can supply a 135 amp 480 volt 3-phase service and the existing automatic transfer switch (ATS) is sized to provide 125 amps. A list of the proposed aeration facility equipment with electrical requirements is shown in Table 3-1.

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TABLE 3-6

McAllister Wellfield Corrosion Control Facility Electrical Requirements (480 volt, 3-phase service)

Electrical Equipment	Power Requirements
7.5 HP Tower No. 1 Blower	11 amps
7.5 HP Tower No. 2 Blower	11 amps
7.5 HP Tower No. 3 Blower	11 amps
7.5 HP Tower No. 4 Blower	11 amps
Telemetry Station	0.625 amps
pH Analyzer	0.625 amps
Lighting	3 amps
Total Electrical Requirements	**48.25 amps**

The existing electrical service is adequate to serve the installation.

INSTRUMENTATION, TELEMETRY, AND CONTROLS

Aeration plant operation will be controlled by a PLC at the aeration site. A discrete signal, indicating that a well is operating, will be generated at the McAllister Wellfield. The PLC will monitor this signal and generate an output to operate the aeration blowers. The number of blowers operating will depend upon the wellfield flow rate.

In addition to operating the blowers, the PLC will monitor inputs from an online pH monitor located downstream of the aeration towers. An alarm will be generated if the treated water pH drops below 7.5.

The aeration facility controls will be integrated with the instrumentation currently located at the Meridian Reservoir Site. The entire aeration facile ty will be monitored remotely from the City shop. A list of items to be monitored by telemetry is included in Table 3-5.

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TABLE 3-7

List of Telemetry Outputs at the Aeration Facility

Parameter	Telemetry Output
Tower 1 Sump High Level	Open/Closed
Tower 2 Sump High Level	Open/Closed
Tower 3 Sump High Level	Open/Closed
Tower 1 Inlet Flow Meter	Flow (4-20mA)
Tower 2 Inlet Flow Meter	Flow (4-20mA)
Tower 3 Inlet Flow Meter	Flow (4-20mA)
pH Monitor (Tower Outlet)	Treated Water pH (4-20mA)
pH Monitor (Reservoir 2 Outlet)	Reservoir Outlet pH (4-20mA)
Reservoir 2 Outlet Flow Meter	Flow (4-20mA)
Tower Inlet Flow	On/Off
Low pH Alarm	Alarm Status
Blower 1 Status	On/Off
Blower 2 Status	On/Off
Blower 3 Status	On/Off

PROJECT CONSTRUCTION COST

Total estimated project cost is $3,502,300. This estimate includes sales tax (7.9 percent), construction contingency (5 percent) and engineering design. See Appendix D for a detailed cost estimate.

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APPENDIX A

SEPA CHECKLIST

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Community Planning & Development
601 4th Avenue E. – PO Box 1967
Olympia WA 98501-1967
Phone: 360.753.8314
Fax: 360.753.8087
cpdinfo@ci.olympia.wa.us
www.olympiawa.gov

STATE ENVIRONMENTAL POLICY ACT DETERMINATION OF NONSIGNIFICANCE (SEPA DNS)

DRAFT

McAllister Wellfield Corrosion Control Facility

Description of Proposal: Construction of 'packed tower aeration water treatment facility' to raise the pH of water, i.e., decrease the acidity, by removing carbon dioxide from wellfield water. The facility would include up to four towers and about a 600 square-foot building with mechanical equipment, plus associated site improvements. This is the site of the McAllister water reservoirs. See accompanying site plan.

Location of Proposal: 9441 Piperhill Drive SE, Olympia, Washington (in the southeast quarter of section 24 and the southwest quarter of section 19 of Township 18 North, Range 1 West); this site is outside the city limits of Olympia; see accompanying vicinity map.

Proponent: City of Olympia

Representative:
Tim Richardson, P.E.
Phone: (360) 753-8749
Email: trichard@ci.olympia.wa.us

Lead Agency: City of Olympia

SEPA Official:
Todd Stamm, Principal Planner
Phone: (360) 753-8597
E-Mail: tstamm@ci.olympia.wa.us

Date of Issue: July 6, 2015

Threshold Determination: The City of Olympia, as lead SEPA agency for this proposal, has determined that with the mitigation described in the proposal; this action probably will **not** have a significant adverse impact upon the environment; therefore an Environmental Impact Statement **is not** required under RCW 43.21C.030(2)(C). The environmental review and SEPA threshold determination of this proposed action are based upon that SEPA checklist dated April 14, 2015, and related information including a geotechnical assessment dated February 2014. This information is available to the public on request. For more information regarding this project, please contact either the project representative or SEPA Official listed above, or see CP&D file #15-0048.

This DNS is **not** a permit. The City of Olympia will not act upon and no permits will be issued for this proposal prior to the appeal deadline. This DNS is issued under Washington Administrative Code 197-11-340. The City will not begin work until after the appeal deadline has expired and any other necessary permits have been obtained.

This determination is based on a presumption that this project will include all mitigation measures described in the proposal and will conform to all applicable standards and regulations. Should any mitigation measure be removed, be infeasible, or be held to be invalid or unconstitutional, a new threshold determination may be required.

Comments regarding this Determination of Non-Significance (DNS) should be directed to the SEPA Official at the address above. If conditions are added, deleted or modified during or following the 14-day comment period, a revised threshold determination may be issued.

COMMENT DEADLINE: 5:00 p.m., Monday, July 20, 2015

APPEAL PROCEDURE: Pursuant to RCW 43.21C.075(3) and Olympia City Code 14.04.160(A), this DNS may be appealed by any agency or aggrieved person. Appeals must be filed with the Community Planning and Development Department at the address above within twenty-one (21) calendar days of the date of issue. Any appeal must be accompanied by a $1,000.00 administrative appeal fee.

APPEAL DEADLINE: 5:00 p.m., Monday, July 27, 2015

Issued by:

TODD STAMM, SEPA OFFICIAL

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Environmental Checklist (SEPA) Cover Form

Olympia

OFFICIAL USE ONLY

Case #: ____________________ Master File #: ____________________ Date Received____________________

Received By: ____________________ Project Planner: ____________________ Related Cases: ____________________

Agency application to be attached to this:

☐ State Environmental Policy Act- Environmental Checklist

For electronic versions, go to: http://www.ecy.wa.gov/programs/sea/sepa/forms.htm

Applicant: City of Olympia (Contact - Tim Richardson) **Phone:** (360) 753-8749

Mailing Address: P.O. Box 1967 City Olympia St WA Zip98507-1967

Email Address: trichard@ci.olympia.wa.us

Project Name: City of Olympia McAllister Wellfield Corrosion Control Facility Project Tax Parcel No. 11824440200

Project Address: 9441 Piperhill Dr. SE, Olympia, WA 98513

Section/Township/Range: SE 1/4 SEC 24 / 18N / R1W and SW 1/4 SEC 19/ 18N / R1W

Total Acres: Parcel is 28.4 acres/area of disturbance is 0.6 acres

Zoning: LD 0-4 Lacey UGA **Shoreline Designation:** UGA **Water Body (if any):** Lake St. Clair(approx 8,420 ft to the SE), McAllister Springs and Lagoon(approx 3,360 ft to the E), Long Lake(approx 9,760 ft to the W), small unnamed kettle lake (1,000 ft to the S), unnamed kettle lake(4,225 ft to the SE)

Initial Permit Type(s):
Special Use, Grading, Building

List of all supplemental reports accompanying this application:

Geotechnical Report (Attachment A)

REQUIRED CHECKLIST ATTACHMENTS

- Title company-certified list of adjacent property owners within 300 feet.
- All fees, including supplemental review fees.
- Reproducible site plans and vicinity map (11"x17" or smaller).
- Five copies of all supplemental reports.

Applicants are required to post the project site with a sign provided by the City within seven days of this application being deemed complete. Please contact City staff for more information

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I affirm that all answers, statements, and information submitted with this application are correct and accurate to the best o my knowledge. I also affirm that I am the owner of the subject site or am duly authorized by the owner to act with respect to this application. Further, I grant permission from the owner to any and all employees and representatives of the City of Olympia and other governmental agencies to enter upon and inspect said property as reasonably necessary to process this application. I agree to pay all fees of the City that apply to this application.

Print Name *Signature* *Date*

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SEPA ENVIRONMENTAL CHECKLIST

Purpose of checklist:

Governmental agencies use this checklist to help determine whether the environmental impacts of your proposal are significant. This information is also helpful to determine if available avoidance, minimization or compensatory mitigation measures will address the probable significant impacts or if an environmental impact statement will be prepared to further analyze the proposal.

***Instructions for applicants*:** [help]

This environmental checklist asks you to describe some basic information about your proposal. Please answer each question accurately and carefully, to the best of your knowledge. You may need to consult with an agency specialist or private consultant for some questions. You may use "not applicable" or "does not apply" only when you can explain why it does not apply and not when the answer is unknown. You may also attach or incorporate by reference additional studies reports. Complete and accurate answers to these questions often avoid delays with the SEPA process as well as later in the decision-making process.

The checklist questions apply to all parts of your proposal, even if you plan to do them over a period of time or on different parcels of land. Attach any additional information that will help describe your proposal or its environmental effects. The agency to which you submit this checklist may ask you to explain your answers or provide additional information reasonably related to determining if there may be significant adverse impact.

Instructions for Lead Agencies:

Additional information may be necessary to evaluate the existing environment, all interrelated aspects of the proposal and an analysis of adverse impacts. The checklist is considered the first but not necessarily the only source of information needed to make an adequate threshold determination. Once a threshold determination is made, the lead agency is responsible for the completeness and accuracy of the checklist and other supporting documents.

Use of checklist for nonproject proposals: [help]

For nonproject proposals (such as ordinances, regulations, plans and programs), complete the applicable parts of sections A and B plus the SUPPLEMENTAL SHEET FOR NONPROJECT ACTIONS (part D). Please completely answer all questions that apply and note that the words "project," "applicant," and "property or site" should be read as "proposal," "proponent," and "affected geographic area," respectively. The lead agency may exclude (for non-projects) questions in Part B - Environmental Elements –that do not contribute meaningfully to the analysis of the proposal.

A. BACKGROUND [help]

1. Name of proposed project, if applicable: [help]

McAllister Wellfield Corrosion Control Facility Project.

2. Name of applicant: [help]

   City of Olympia

3. Address and phone number of applicant and contact person: [help]

   Contact: Tim Richardson, P.E., Project Manager

   P.O. Box 1967, Olympia, WA 98507-1967

   (360) 753-8749

4. Date checklist prepared: [help]

   March 20, 2015

5. Agency requesting checklist: [help]

   City of Olympia

6. Proposed timing or schedule (including phasing, if applicable): [help]

   The estimated start date of the project is August 2015. In August 2015, the clearing limits will be marked, construction access will be established, sediment controls will be installed, and demolition, grading and utility construction will take place. In September 2015 through April 2016, the facility will be constructed. Physical completion is estimated to occur by June 2016.

7. Do you have any plans for future additions, expansion, or further activity related to or connected with this proposal? If yes, explain. [help]

   Yes. A fourth packed tower aerator will be added upon expansion of the McAllister Wellfield to a capacity of 23 MGD.

8. List any environmental information you know about that has been prepared, or will be prepared, directly related to this proposal. [help]

   Engineering Abbreviated Drainage Plan, Geotechnical Assessment.

9. Do you know whether applications are pending for governmental approvals of other proposals directly affecting the property covered by your proposal? If yes, explain. [help]

   No

10. List any government approvals or permits that will be needed for your proposal, if known. [help]

    Thurston County Special Use Permit, Grading Permit, Building Permit.

    Washington State Department of Health Project Approval.

    Washington State Department of Ecology Construction Stormwater NPDES Permit

    Olympic Region Clean Air Agency – Air Quality Permit

11. Give brief, complete description of your proposal, including the proposed uses and the size of the project and site. There are several questions later in this checklist that ask you to describe certain aspects of your proposal. You do not need to repeat those answers on this page. (Lead agencies may modify this form to include additional specific information on project description.) [help]

    The City of Olympia is proposing the development of a packed tower aeration water treatment facility to raise the pH of the water supplied by the McAllister Wellfield. The proposed facility will

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remove carbon dioxide from the water to raise the pH and reduce corrosion of piping in the City's water distribution system. The McAllister Wellfield Corrosion Control Facility will include the construction of three packed tower aerators, and site piping to connect the packed towers to the transmission main and Meridian Reservoirs, as well as a 550 square foot CMU building to house centrifugal blowers associated with the aeration tower. In addition, this project will construct an asphalt access road between the existing Meridian Valve House, the aeration towers and blower building. The existing site access road from Piper Hill Drive will also be repaved.

12. Location of the proposal. Give sufficient information for a person to understand the precise location of your proposed project, including a street address, if any, and section, township, and range, if known. If a proposal would occur over a range of area, provide the range or boundaries of the site(s). Provide a legal description, site plan, vicinity map, and topographic map, if reasonably available. While you should submit any plans required by the agency, you are not required to duplicate maps or detailed plans submitted with any permit applications related to this checklist. [help]

The corrosion control facility will be constructed at the existing Meridian Reservoir Site, northwest of the McAllister Wellfield. The property address is 9441 Piperhill Dr. SE, and is located in a low density residential area within the City of Lacey UGA. Site plan and vicinity maps are attached.

B. ENVIRONMENTAL ELEMENTS [help]

1. Earth

a. General description of the site [help]

(circle one): **Flat**, rolling, hilly, steep slopes, mountainous,

Other: The project site is generally flat; however, there are steep slopes located directly to the east of the proposed corrosion control facility.

b. What is the steepest slope on the site (approximate percent slope)? [help]

Approximately 55%.

c. What general types of soils are found on the site (for example, clay, sand, gravel, peat, muck)? If you know the classification of agricultural soils, specify them and note any agricultural land of long-term commercial significance and whether the proposal results in removing any of these soils. [help]

Sandy gravels, sand and gravels, and glacial till.

d. Are there surface indications or history of unstable soils in the immediate vicinity? If so, describe. [help]

None

e. Describe the purpose, type, total area, and approximate quantities and total affected area of any filling, excavation, and grading proposed. Indicate source of fill. [help]

A fill pad will be created under the proposed aeration towers and blower building. Additionally, minor site grading will be necessary to accommodate the onsite access road. Asphalt base and crushed surface top course (CSTC) and hot mix asphalt (HMA) for construction of access road. The total amount of fill material necessary to complete the proposed project is approximately 1,300 cubic yards. Possible earth moving for construction of temporary construction access roads using on-site materials.

f. Could erosion occur as a result of clearing, construction, or use? If so, generally describe. [help]

Due to the highly permeable nature of the soils in this area, it is unlikely that erosion will occur during

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construction or after clearing and grubbing. Erosion control measures will be put in place along slopes as needed during construction. Silt fencing will be installed around the project area perimeter.

g. About what percent of the site will be covered with impervious surfaces after project construction (for example, asphalt or buildings)? [help]

Final impervious area on the parcel is 74,570 square feet or approximately 6% of the total area of the parcel. 67,570 square feet already exist on the parcel, or 5.5% of the total area. Proposed impervious area is 7,000 square feet, .5% of the total area.

h. Proposed measures to reduce or control erosion, or other impacts to the earth, if any: [help]

For impacts related to construction, erosion control measures will include silt fences, and compost berm. All unworked and exposed soils will be stabilized to prevent erosion. Furthermore, Best Management Practices will be implemented as set forth in the Drainage Design and Erosion Control Manual for Thurston Region, Washington.

2. Air

a. What types of emissions to the air would result from the proposal during construction, operation, and maintenance when the project is completed? If any, generally describe and give approximate quantities if known. [help]

Hydrocarbon emissions from internal combustion engines during construction, and dust from earth moving.

b. Are there any off-site sources of emissions or odor that may affect your proposal? If so, generally describe. [help]

None known.

c. Proposed measures to reduce or control emissions or other impacts to air, if any: [help]

Proper mufflers and air emissions control devices will be maintained on equipment. Disturbed areas will be wetted to control dust.

3. Water

a. Surface Water: [help]

1) Is there any surface water body on or in the immediate vicinity of the site (including year-round and seasonal streams, saltwater, lakes, ponds, wetlands)? If yes, describe type and provide names. If appropriate, state what stream or river it flows into. [help]

   None.

2) Will the project require any work over, in, or adjacent to (within 200 feet) the described waters? If yes, please describe and attach available plans. [help]

   No.

3) Estimate the amount of fill and dredge material that would be placed in or removed from surface water or wetlands and indicate the area of the site that would be affected. Indicate the source of fill material. [help]

   None.

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4) Will the proposal require surface water withdrawals or diversions? Give general description, purpose, and approximate quantities if known. [help]

No.

5) Does the proposal lie within a 100-year floodplain? If so, note location on the site plan. [help]

No.

6) Does the proposal involve any discharges of waste materials to surface waters? If so, describe the type of waste and anticipated volume of discharge. [help]

None.

b. Ground Water:

1) Will groundwater be withdrawn from a well for drinking water or other purposes? If so, give a general description of the well, proposed uses and approximate quantities withdrawn from the well. Will water be discharged to groundwater? Give general description, purpose, and approximate quantities if known. [help]

No ground water will be withdrawn or water discharged to groundwater, from the Corrosion Control Facility. This facility will treat water from the McAllister Wellfield. The Meridian Reservoirs will receive treated water from the facility.

2) Describe waste material that will be discharged into the ground from septic tanks or other sources, if any (for example: Domestic sewage; industrial, containing the following chemicals; agricultural; etc.). Describe the general size of the system, the number of such systems, the number of houses to be served (if applicable), or the number of animals or humans the system(s) are expected to serve. [help]

None.

c. Water runoff (including stormwater):

1) Describe the source of runoff (including storm water) and method of collection and disposal, if any (include quantities, if known). Where will this water flow? Will this water flow into other waters? If so, describe. [help]

Soils are very porous and there is limited grading work, thus very little, if any, runoff is expected as a result of construction work. All stormwater and runoff generated onsite will be infiltrated and dispersed onsite. Once construction is completed, runoff from buildings will be dispersed through a dispersion trench.

2) Could waste materials enter ground or surface waters? If so, generally describe. [help]

Proper construction practices will prevent waste materials from entering ground or surface waters. An on-site spill that is not contained could potentially enter surface or shallow groundwater. The City requires an approved on-site emergency response plan as part of the paperwork the contractor must supply before beginning construction on the project. The plan will address actions if a spill occurs.

3) Does the proposal alter or otherwise affect drainage patterns in the vicinity of the site? If so, describe.

No, the proposed project will utilize existing drainage swales located on the reservoir site. Stormwater not directed to existing swales will be dispersed over the ground surface. Drainage impacts will be confined to the project site.

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d. Proposed measures to reduce or control surface, ground, and runoff water, and drainage pattern impacts, if any:

All storm drain inlets made operable during construction will be protected so that stormwater runoff will not enter the conveyance system without being filtered first. Runoff from gravel paved areas is either dispersed from the edge of the paved area to the surrounding grass or captured by swales. The swales convey runoff to a detention pond located immediately south of Reservoir No.

4. **Plants** [help]

a. Check the types of vegetation found on the site: [help]

___x_deciduous tree: alder, maple, aspen, other
___x_evergreen tree: fir, cedar, pine, other
____shrubs
__x_grass
__x_pasture
____crop or grain
____ Orchards, vineyards or other permanent crops.
____ wet soil plants: cattail, buttercup, bullrush, skunk cabbage, other
____water plants: water lily, eelgrass, milfoil, other
____other types of vegetation

b. What kind and amount of vegetation will be removed or altered? [help]

Some grass will be removed. No native vegetation will be disturbed.

c. List threatened and endangered species known to be on or near the site. [help]

None.

d. Proposed landscaping, use of native plants, or other measures to preserve or enhance vegetation on the site, if any: [help]

Landscaping and replacement of vegetation will be considered during the final design, including use of native plants. At a minimum, disturbed areas will be hydroseeded.

e. List all noxious weeds and invasive species known to be on or near the site.

None Known

5. **Animals**

a. List any birds and other animals which have been observed on or near the site or are known to be on or near the site. Examples include: [help]

birds: **hawk,** heron, **eagle, songbirds,** other: **crows.**

A survey of birds was not conducted. Several of the birds listed may exist in the project area.

mammals: **deer**, bear, elk, beaver, other: **racoon, opossum.**

A survey of mammals was not conducted. Several of the mammals listed may exist in the project area.

fish: bass, salmon, trout, herring, shellfish, other ________

None.

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b. List any threatened and endangered species known to be on or near the site. [help]

None.

c. Is the site part of a migration route? If so, explain. [help]

Yes, the entire Puget Sound area is part of the Pacific Flyway.

d. Proposed measures to preserve or enhance wildlife, if any: [help]

None proposed, since limited habitats will be disturbed.

e. List any invasive animal species known to be on or near the site.

None known

6. **Energy and natural resources**

a. What kinds of energy (electric, natural gas, oil, wood stove, solar) will be used to meet the completed project's energy needs? Describe whether it will be used for heating, manufacturing, etc. [help]

Electrical energy will be used in the blower building and at the aeration towers. Gasoline and diesel fuel will be used for construction equipment and the emergency generator.

b. Would your project affect the potential use of solar energy by adjacent properties? If so, generally describe. [help]

No.

c. What kinds of energy conservation features are included in the plans of this proposal? List other proposed measures to reduce or control energy impacts, if any: [help]

Energy efficient equipment will be used wherever possible. The centrifugal blowers will be equipped with premium efficiency motors.

7. **Environmental health**

a. Are there any environmental health hazards, including exposure to toxic chemicals, risk of fire and explosion, spill, or hazardous waste, that could occur as a result of this proposal? If so, describe. [help]

Proper construction practices will prevent an onsite spill from entering ground or surface waters. The City requires an approved onsite emergency response plan as part of the paperwork the contractor must submit before beginning construction on the project. The plan will address actions if an on-site were to occur.

1) Describe any known or possible contamination at the site from present or past uses.

None Known

2) Describe existing hazardous chemicals/conditions that might affect project development and design. This includes underground hazardous liquid and gas transmission pipelines located within the project area and in the vicinity.

None Known

3) Describe any toxic or hazardous chemicals that might be stored, used, or produced during the project's development or construction, or at any time during the operating life of the project.

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None

4) Describe special emergency services that might be required.

   None anticipated.

5) Proposed measures to reduce or control environmental health hazards, if any:

   Pollutants will be promptly contained and disposed of to prevent contamination of water and stormwater.

b. **Noise**

1) What types of noise exist in the area which may affect your project (for example: traffic, equipment, operation, other)? [help]

   None.

2) What types and levels of noise would be created by or associated with the project on a short-term or a long-term basis (for example: traffic, construction, operation, other)? Indicate what hours noise would come from the site. [help]

   Short-term noise will occur during construction, from construction activities. This will occur during normal business hours. Long-term noise will consist of background noise from the centrifugal blowers. This noise will occur 24 hours per day intermittently, and 7 days per week. Noise related to the blowers will be within allowable noise standards.

3) Proposed measures to reduce or control noise impacts, if any: [help]

   The blowers will be housed in a CMU building. Most of the noise produced by the blowers will be attenuated by the blower building.

8. **Land and shoreline use**

a. What is the current use of the site and adjacent properties? Will the proposal affect current land uses on nearby or adjacent properties? If so, describe. [help]

   The site is located in a low density residentially zoned area.

b. Has the project site been used as working farmlands or working forest lands? If so, describe. How much agricultural or forest land of long-term commercial significance will be converted to other uses as a result of the proposal, if any? If resource lands have not been designated, how many acres in farmland or forest land tax status will be converted to nonfarm or nonforest use? [help]

   No.

   1) Will the proposal affect or be affected by surrounding working farm or forest land normal business operations, such as oversize equipment access, the application of pesticides, tilling, and harvesting? If so, how:

      No.

c. Describe any structures on the site. [help]

   Existing concrete valve house and two four million gallon pre-stressed concrete reservoirs.

d. Will any structures be demolished? If so, what? [help]

   No.

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e. What is the current zoning classification of the site? [help]

The site is located in a residentially zoned area (Low Density Residential 0-4).

f. What is the current comprehensive plan designation of the site? [help]

Lacey UGA.

g. If applicable, what is the current shoreline master program designation of the site? [help]

None. Lacey UGA

h. Has any part of the site been classified as a critical area by the city or county? If so, specify. [help]

The site is located within a Critical Aquifer Recharge Area, under the Thurston County Critical Areas Ordinance.

i. Approximately how many people would reside or work in the completed project? [help]

1 to 2 people would visit the site on a daily basis.

j. Approximately how many people would the completed project displace? [help]

None.

k. Proposed measures to avoid or reduce displacement impacts, if any: [help]

None.

. Proposed measures to ensure the proposal is compatible with existing and projected land uses and plans, if any: [help]

None.

m. Proposed measures to ensure the proposal is compatible with nearby agricultural and forest lands of long-term commercial significance, if any:

None.

9. **Housing**

a. Approximately how many units would be provided, if any? Indicate whether high, middle, or low-income housing. [help]

N/A.

b. Approximately how many units, if any, would be eliminated? Indicate whether high, middle, or low-income housing. [help]

N/A.

c. Proposed measures to reduce or control housing impacts, if any: [help]

N/A.

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10. Aesthetics

a. What is the tallest height of any proposed structure(s), not including antennas; what is the principal exterior building material(s) proposed? [help]

The aeration towers will each be approximately 37 feet tall. They will be constructed of fiberglass and provided with a pigmented gel coat.

b. What views in the immediate vicinity would be altered or obstructed? [help]

None.

c. Proposed measures to reduce or control aesthetic impacts, if any: [help]

A greenbelt surrounds the entire site, obscuring existing and proposed structures on the site. The proposed structures will be constructed within the existing cleared area and all the existing vegetative screening will remain.

11. Light and glare

a. What type of light or glare will the proposal produce? What time of day would it mainly occur? [help]

None.

b. Could light or glare from the finished project be a safety hazard or interfere with views? [help]

No.

c. What existing off-site sources of light or glare may affect your proposal? [help]

None.

d. Proposed measures to reduce or control light and glare impacts, if any: [help]

None.

12. Recreation

a. What designated and informal recreational opportunities are in the immediate vicinity? [help]

None.

b. Would the proposed project displace any existing recreational uses? If so, describe. [help]

No.

c. Proposed measures to reduce or control impacts on recreation, including recreation opportunities to be provided by the project or applicant, if any: [help]

None.

13. Historic and cultural preservation

a. Are there any buildings, structures, or sites, located on or near the site that are over 45 years old listed in or eligible for listing in national, state, or local preservation registers located on or near the site? If so, specifically describe. [help]

The Meridian Reservoir No. 1 is on the Washington State Historic Property Inventory. The Reservoir was replaced in 2005. However, the Meridian Valve House remains onsite and is over 50 years old. The proposed work will not affect the Meridian Valve House.

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b. Are there any landmarks, features, or other evidence of Indian or historic use or occupation? This may include human burials or old cemeteries. Are there any material evidence, artifacts, or areas of cultural importance on or near the site? Please list any professional studies conducted at the site to identify such resources. [help]

None.

c. Describe the methods used to assess the potential impacts to cultural and historic resources on or near the project site. Examples include consultation with tribes and the department of archeology and historic preservation, archaeological surveys, historic maps, GIS data, etc. [help]

None.

d. Proposed measures to avoid, minimize, or compensate for loss, changes to, and disturbance to resources. Please include plans for the above and any permits that may be required.

None.

14. Transportation

a. Identify public streets and highways serving the site or affected geographic area and describe proposed access to the existing street system. Show on site plans, if any. [help]

The access road to the facility is located off of Piperhill Drive SE.

b. Is the site or affected geographic area currently served by public transit? If so, generally describe. If not, what is the approximate distance to the nearest transit stop? [help]

No. approx 1.5 miles

c. How many additional parking spaces would the completed project or non-project proposal have? How many would the project or proposal eliminate? [help]

2

d. Will the proposal require any new or improvements to existing roads, streets, pedestrian, bicycle or state transportation facilities, not including driveways? If so, generally describe (indicate whether public or private). [help]

No

e. Will the project or proposal use (or occur in the immediate vicinity of) water, rail, or air transportation? If so, generally describe. [help]

No. BNSF Railway is approx 1,530 ft to the N

f. How many vehicular trips per day would be generated by the completed project or proposal? If known, indicate when peak volumes would occur and what percentage of the volume would be trucks (such as commercial and nonpassenger vehicles). What data or transportation models were used to make these estimates? [help]

After construction is complete, there will be approximately 1 vehicular visit per day.

g. Will the proposal interfere with, affect or be affected by the movement of agricultural and forest products on roads or streets in the area? If so, generally describe.

None.

h. Proposed measures to reduce or control transportation impacts, if any: [help]

None.

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15. **Public services**

a. Would the project result in an increased need for public services (for example: fire protection, police protection, public transit, health care, schools, other)? If so, generally describe. [help]

No.

b. Proposed measures to reduce or control direct impacts on public services, if any. [help]

None.

16. **Utilities**

a. Circle utilities currently available at the site: [help]

electricity, natural gas, **water**, refuse service, telephone, sanitary sewer, **septic system**, other ____________

b. Describe the utilities that are proposed for the project, the utility providing the service, and the general construction activities on the site or in the immediate vicinity which might be needed. [help]

General construction activities for this project will include grading, excavation, construction of the CMU blower building, aeration towers, and foundation pad.

C. SIGNATURE [HELP]

The above answers are true and complete to the best of my knowledge. I understand that the lead agency is relying on them to make its decision.

Signature: ____

Name of signee ____

Position and Agency/Organization ________________________________

Date Submitted: ____________

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LIST OF ATTACHMENTS:

ATTACHMENT A – GEOTECHNICAL REPORT

ATTACHMENT B – VICINITY MAP

ATTACHMENT C – SITE PLAN MAP

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ATTACHMENT A

GEOTECHNICAL REPORT

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REPORT

CITY OF OLYMPIA MCALLISTER WELLFIELD CORROSION CONTROL FACILITY

Olympia Meridian Reservoir Site - Geotechnical Assessment

DRAFT

Submitted To: Gray & Osborne, Inc.
2102 Carriage Drive SW, Building I
Olympia, WA 98502

Submitted By: Golder Associates Inc.
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Distribution: Mike Johnson, PE, Gray & Osborne, Inc.
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Date: February 2014

Project No. 123-9975501

Golder Associates

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EXECUTIVE SUMMARY

Golder Associates Inc. (Golder) was retained by Gray & Osborne, Inc. (G&O) to conduct a geotechnical investigation for the Meridian Reservoir Corrosion Control Facility (CCF) project near Lacey, Washington. This development includes construction of three fiberglass packed towers (expandable to four in the future) and potentially a 1,000 square-foot CMU building used to house the blowers and controls for the facility.

The intent of this investigation was to evaluate the subsurface conditions and provide construction considerations and recommendations for the proposed CCF.

Golder advanced a total of 4 exploratory test pits (TP-01 through TP-04). These explorations encountered gravelly sand and sandy gravels to depths of approximately 8-10 feet, underlain by glacial till. A lens of very dense glacial till was encountered in TP-03 at 0.5 - 3.5 feet, underlain by sandy gravels. Results from Golder's subsurface investigation, including dynamic cone penetrometer testing (DCPT), and previous subsurface data obtained by others, were used to develop soil strength parameters for design of the proposed CCF.

Slab-on-grade foundations will be suitable for use at the site, provided a minimum overexcavation and backfill of 24 inches below foundation elements is performed to remove loose on site soils. Should additional uplift capacity be required to resist overturning, turndowns should be considered first, prior to helical anchor foundation elements. Installing helical anchors into the native tills underlying the site could prove difficult due to the likely presence of cobbles and boulders.

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1.0 INTRODUCTION

This report presents the results of our geotechnical investigation and foundation design for the Olympia Meridian Reservoir Corrosion Control Facility Project planned east of Olympia, WA. The project involves construction of a corrosion control facility. It is our understanding that this facility will consist of three fiberglass packed towers, with the opportunity to expand to four towers in the future. The packed towers will be 14 feet diameter by 38 feet tall and have a maximum weight of 170 kips. Towers will be mounted on a concrete slab-on-grade, approximately 80 feet by 27 feet, and the fully loaded towers will impart a load of around 315 psf. Additionally, a new 1,000 sf CMU building will be constructed north of the corrosion control facility to house the blowers and controls for the facility.

1.1 Purpose

The purpose of this report was to provide subsurface geotechnical information and geotechnical recommendations to Gray & Osborne, Inc. for the construction of the proposed facility. The primary geotechnical issues addressed by this report include:

- Condition and type of subsurface soils underlying the proposed facility; and
- Foundation design and considerations for the proposed facility

1.2 Scope of Work

The scope of work completed for the geotechnical site investigation and engineering analysis were performed in accordance with our May 1, 2011 Change Order #1 scope and cost estimate provided to Gray and Osborne, and includes the following items:

- Review of existing geotechnical reports for the Meridian Reservoir site as provided by the City of Olympia.
- Preparation for field investigation including development of a site-specific health and safety plan, utility locate through the One-Call System and a private utility locator, coordination with city personnel for site access, and determine location of test pits.
- Provided field oversight during advancement of 4 test pits, performed Dynamic Cone Penetrometer Test (DCPT) during test pit excavation, and collected soil samples from each test pit.
- Observed and recorded any groundwater conditions encountered during the advancement of the test pits.
- Geotechnical laboratory testing on selected soil samples, including moisture content determination and grain-size analysis.
- Developed seismic design parameters as required by Chapter 16 of the 2012 International Building Code (IBC).
- Developed recommendations regarding foundation support of the proposed facility.
- Developed construction considerations and recommendations for the proposed facility.

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- Prepared this draft geotechnical report summarizing the investigation and engineering analysis for Gray and Osborne review and comment. Upon receipt of comments from Gray and Osborne, Golder will prepare a final geotechnical report.

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2.0 FIELD AND LABORATORY INVESTIGATIONS

2.1 Previous Investigations

Historical reports in the vicinity of the site were provided to Golder by the City of Olympia. These reports were conducted for the design and construction of the existing water tanks and reservoir No. 1. Golder has reviewed the borings and geotechnical information from the following reports:

- AGRA Earth & Environmental (1997) Geotechnical Engineering Report, Meridian Heights Water Tank, Thurston County, Washington, February 14, 1197, prepared for Economic and Engineering Services, Inc. (2 boreholes, 13 test pits)
- CH2M Hill (2003) Geotechnical Data Report, Meridian Reservoir No. 1 Replacement, May, 2003, prepared for City of Olympia, Washington. (2 borings, 3 percolation tests)

The soil conditions reflected in the above investigations are consistent with sediments deposited in glacial and alluvial environments.

2.2 Current Investigation

Golder was on site on November 19, 2013 to excavate test pits within the site boundary. The purpose of the test pits was to evaluate the subsurface soils for suitability as foundation materials. The test pits were excavated to depths between 9 and 10 feet below the ground surface (bgs), with the exception of G-TP-04 which was terminated at 7 feet bgs due to encountering a utility pipe. Dynamic Cone Penetrometer Tests (DCPT) were performed in each test pit reaching depths ranging from 0 feet to 10 feet BGS.

Excavation of the test pits was performed by Clearcreek Contractors, Inc. of Everett, Washington under the observation of a Golder representative, who developed test pit records of the subsurface conditions encountered. Soil samples were collected as grab samples of the subsurface soils taken directly from excavated soils. All samples were field inspected, stored in moisture-proof bags, and transported to Golder's geotechnical laboratory in Redmond, Washington for storage and testing. The test pit records were developed from the field observations and test results of the samples returned from the laboratory. The test pit records are provided in Appendix A. Test pits were backfilled with excavated soils and compacted with the excavator bucket.

2.3 Laboratory Testing

Selected soil samples collected during the field exploration program were tested to assist with classifications. Grab samples collected by the on-site engineer were submitted to our Redmond, Washington laboratory. The laboratory testing program included the following tests:

- Soil classification, in general accordance with ASTM D 2487. Exceptions were made in USCS group name and symbols, as presented in the Golder Soil Classification System, Appendix A;
- Natural moisture content tests in accordance with ASTM D 2216 of all samples;

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- Grain size distribution in accordance with ASTM D 422 to confirm field classification and evaluate permeability of coarse grained soils;

Results of the laboratory tests are summarized on the Test Pit Records, Appendix A. Complete individual laboratory test results are presented in Appendix B.

Table 2-1: Grain Size Analyses Summary

Exploration Number	Depth (ft)	Percent of Gravel	Percent of Sand	Percent Passing #200 Sieve	USCS
TP-01	3.0	47.7%	42.5%	9.8%	SP
TP-01	5.0	66.4%	23.0%	10.6%	GP
TP-02	4.0	69.6%	20.8%	9.7%	GP
TP-02	8.0	62.7%	26.3%	11.1%	GP
TP-03	5.5	59.9%	27.7%	12.4%	GP
TP-03	9.5	60.1%	28.1%	11.9%	GP
TP-04	5.0	54.8%	32.2%	13.0%	GP
TP-04	7.0	53.0%	39.7%	10.9%	GP

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3.0 SITE DESCRIPTION

3.1 Regional Geology

The Meridian Reservoir site lies within the northeastern part of Thurston County, which borders the southern extent of Puget Sound. The present day land surface is largely the result of erosion and deposition processes that have operated since the last glaciation that occurred in the Frasier Glaciation. This event, known as the Vashon Stade, dated from about 15,000 years before present. The landscape is generally low-lying, with the topography ranging from mean sea level (msl) along the shoreline of the Puget Sound to more than 360 feet above msl to the south near Fort Lewis military reservation and above 460 feet msl at Tumwater Hill. This glacial-drift plain is dissected by two regional rivers (the Nisqually and Deschutes), numerous small tributary streams, glacial lakes, ponds, wetlands and springs. Large portions of the region are rural vegetated, consisting of coniferous forests and open prairies, as well as urban areas.

3.2 Site Geology

The project site is located near Highway 510 on a hill west of McAllister Springs near Olympia, Washington (Figure 1). The existing on-site facilities are situated on a relatively level fenced, lawn area which appears to have been formed by cutting the top off of a low knoll and placing the material around its periphery. Within the proposed CCF footprint, ground surface elevations range from approximately 292 to 296 feet above the National Geodetic Vertical Datum of 1929 (NGVD29).

Review of geologic the geologic map of the area (Walsh, et. al., 2003) indicates the site consists of Vashon glacial and Pre-Vashon sequence, consisting of Vashon Recessional Outwash (Qgo) and Vashon Till (Qgt). The Vashon Recessional Outwash consists of sand and gravel that may contain boulders, silt, clay, and laminated lacustrine deposits. Locally, this unit exists near the valley bluffs, is generally less than 25 feet thick and may not contain groundwater. The Vashon Till consists of grey compact sand, gravel, silt, clay up to 150 feet thick (Figure 2).

3.3 Surface Conditions

The site is located on a lot of approximately 5 acres. Elevation at the site varies from approximate elevations 283 feet in the northeast corner (near reservoir 2) to 295 feet northeast of Reservoir 1. The ground surface is covered with light grass, with exposed sand and gravel in areas.

3.4 Subsurface Conditions

Detailed descriptions of the subsurface conditions encountered at each test pit are presented in the Test Pit Record Sheets, Appendix A. Classification and identification of soils has been based on USCS and Golder Soil Classification System. In some cases, the stratigraphic boundaries shown on the Test Pit

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Record Sheets represent transitions between soil types rather than distinct lithological boundaries. Subsurface conditions are likely to vary between individual test pit locations (Figure 3).

Geologic units encountered during the subsurface exploration include approximately 6 inches of vegetation and topsoil underlain by sandy gravels, sand and gravels, and glacial till. Generalized descriptions of these units are presented below.

- **Topsoil and Surficial Soils:** Approximately 6 inches of topsoil, silty sands and gravels, were encountered across the exploration locations at the site. Underlying the topsoil was sand and gravel to sandy gravels containing some silt.
- **Gravelly Sand (Glacial Outwash Fill):** This unit was varying in thickness underlying the topsoil in each test pit, with exception to test pit 3, which encountered a cap (up to depth of 3.5 ft in thickness) of cemented glacial till. These soils are very loose to compact, gray to brown gravelly sands to sandy gravels with some silt; fines content near 10%.
- **Sandy Gravel (Glacial Outwash):** This soil unit was marked by a change in color grading from gray to orange and brown, distinguishing it from the overlying soils. This soil unit also contained a larger amount of coarse gravel than the overlying layer. These soils are very loose to compact sandy gravels with some silt; fines contents of 10% to 13%.
- **Glacial Till:** Very dense glacial till soil was encountered in test pits TP-1, TP-2, and TP-3. TP-3 encountered a very thick cap of cemented glacial till which was very difficult to excavate. Test pits 1 and 2 met refusal in the till at depths of 10.0 feet and 9.0 feet respectively.

3.5 Dynamic Cone Penetrometer Tests

Dynamic Cone Penetrometer Tests (DCPT) were performed at the location of each test pit, within the area of the proposed Corrosion Control Facility and CMU Building. The DCPT is a widely used device to determine in-situ strength properties of base materials and subgrade soils. The four main components of the DCPT include the cone, rod, anvil, and hammer. The cone is attached to one end of the DCPT rod while the anvil and hammer are attached to the other end. The dynamic cone penetrometer uses a 35-lb steel mass that falls 15 inches against the anvil to drive a 1.4 inch diameter cone into the soil. The blows required to drive a cone a depth of 10 cm has been correlated to N values derived from the Standard Penetration Test. Records of the DCPT test results are included in Appendix A. Test results yielded blow counts of 2 to 31, which correlates to very loose to dense soil conditions within the upper 10 feet of the site.

3.6 Groundwater Conditions

Groundwater conditions were monitored during the excavation of the test pits. At the time of the test pit excavations, seepage into the pits was observed in test pits TP-2, TP-3, and TP-4. The rate of seepage into the pits was very slow and entered the test pits from the west and north sides of the pits. The source of the seepage into the test pits could be due to perched groundwater conditions on site. We anticipate that perched groundwater conditions could develop above the soil interface with the very dense glacial till.

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The perching of groundwater can occur when a relatively impermeable soil layer impedes and slows the downward infiltration of groundwater causing it to migrate laterally in the overlying, more permeable soils.

Based upon Golder's current investigation and laboratory testing, ground water levels appear to be below the bottom of the test pit excavations and based on previous investigations, completed by AGRA, that ground water will be at least 35 feet below ground surface. Groundwater levels would likely fluctuate in response to precipitation patterns (AGRA, 1997).

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4.0 SEISMIC DESIGN CRITERIA

4.1 Regional Seismicity

The Pacific Northwest has four types of seismic sources due to the presence of the Cascadia Subduction Zone (CSZ). These sources include (1) the subduction zone megathrust which represents the interface between the down-trending Juan de Fuca plate and the overriding North American Plate; (2) faults located within the Juan de Fuca plate (referred to as the intraplate or intraslab region); (3) crustal faults principally in the North American plate; and (4) volcanic sources beneath the Cascade Range (Silva and Wong, 1998).

4.2 Local Seismicity

Using the US Geological Survey (USGS) guidelines (https://geohazards.usgs.gov/deaggint/2008/; USGS 2008), the Southern Whidbey Fault Zone (Mw 7.0) and subduction zone earthquake (Mw 9.0) were found to be the predominant seismic sources for the site. Site mean peak ground accelerations (PGA) were estimated for return periods of 475 year (500-year event) and 2,475 year (2,500-year event) probabilistic events. USGS deaggregation of the site resulted in a mean PGA of 0.3g and 0.55g for the 500 and 2,500 year events, respectively. Output from the USGS Seismic Deaggregation tool can be found in Appendix C.

4.3 2012 IBC Seismic Design

We recommend that all structures on the site be evaluated in accordance with the seismic design provisions presented in Chapter 16 of the 2012 version of the International Building Code (IBC). The site is classified by the upper 100 feet of soil at the site. The deepest boring completed at our site from previous investigations was 51 feet deep and without shear wave velocity data the site is best classified as "Stiff Soil Profile", corresponding to a Soil Site Class D. This is based on the calculated average N-Value is in the range of $15 \leq \overline{N} \leq 50$ within the upper 100 feet of the site soils. Provided in Table 4-1 are recommended values, based on the site location and conditions described above, for seismic design of the project for use in accordance with Section 1613 of the 2012 IBC.

The following design parameters are based on the peak ground acceleration (PGA), the 0.2 second spectral acceleration (S_s), and the 1.0 second spectral acceleration (S_1) for the project site latitude of North 47.03, longitude West 122.74. These parameters were taken from the United States Geological Survey website for Earthquake Hazards Program Probabilistic Hazard Lookup by latitude and longitude (USGS, 2008). The following (un-modified for site class B) interpolated probabilistic ground motion values for the Maximum Considered Earthquake (2 percent probability of exceedance in 50 years) can be used for seismic design:

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Table 4-1: 2012 IBC Seismic Design Values Site Class B

Design Value	(g)
Site Class	D
Peak Ground Acceleration	0.554
Short (0.2 second) Spectral Response (S_S)	1.297
Long (1.0 second) Spectral Response (S_1)	0.523

1. Maps in the 2012 IBC are provided for Site Class B. Adjustments for other Site Classes can be made as needed.

4.4 Liquefaction Assessment

Liquefaction is a process that can occur when soils lose shear strength for short periods of time during a seismic event. Ground shaking of sufficient strength and duration can result in the loss of grain-to-grain contact and a rapid increase in pore water pressure, causing the soil to behave as a fluid. Soils with a potential for liquefaction are predominately silt and sand sized, must be loose, and be below the groundwater table.

Based on our field exploration and explorations conducted in the immediate vicinity of the project site, the soils below the water table on-site are generally very dense. In our judgment the risk of liquefaction induced settlements at this site is considered to be low.

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5.0 FOUNDATION DESIGN RECOMMENDATIONS

5.1 Shallow Foundations – General

Conventional, shallow isolated or continuous spread footings may be used throughout the site provided they are founded on compact to dense native soils, or on properly compacted structural fill placed over these soils. Footings should not be founded on topsoil, loose native soils, or previously placed uncontrolled fill. Based on test pit data generated on the project site, the relatively lightly loaded tank foundation and CMU building can be supported using a slab-on-grade foundation system bearing on a minimum of two feet of structural fill.

In order to provide two feet of structural fill below foundation elements, the foundation bearing soils will need to be overexcavated to a minimum depth of two feet below the bottom of slab elevations and backfilled following our recommendations in section 6.3 Earthworks. Prior to the placement of the structural fill, the surface exposed at the base of the overexcavation should be observed by Golder. The width of the foundation overexcavation should extend beyond the width of the foundation elements by at least the depth of the overexcavation.

If organic or debris-laden soil is encountered at the overexcavation subgrade elevation, additional overexcavation may be required. The depth of additional overexcavation will need to be determined in the field at the time of construction. Therefore, localized overexcavation in excess of two feet may be necessary where debris or organic soil is encountered at the foundation overexcavation subgrade elevation.

Conventional foundations should be designed based on the following parameters:

Maximum Allowable Bearing Pressures for Isolated Spread Footings FS=3.0:

Structural Fill………………………………………………………………	2,500 psf

Table 5-1: Settlement Estimates for Footings[1]

Bearing Pressure, q (psf)	Estimated Settlement, δ (inches)
Up to 600 psf	less than 0.5 in

1. For footings with a width equal to or less than 27 feet

The bearing capacity values may be increased by 1/3 for short-term wind or seismic loading.

Minimum Embedment for Frost Protection:

Perimeter footings……………………………………………………………	18 inches
Interior footings (below exterior grades)…………………………………	12 inches

Minimum Footing Widths:

Perimeter footings……………………………………………………………	18 inches
Interior isolated footings……………………………………………………	24 inches

Based on the anticipated loading of 315 psf, we estimate settlement due to dead and live loads, will be approximately 0.5 inch with differential settlement of about 0.25 inches. Because most of this settlement will occur during construction, as the dead loads are applied, and during the initial filling of the tanks, we anticipate any long term settlements will be minor. Settlement analysis was performed using the program Settle3D Version 2.0 by Rocscience, Inc. This program utilizes the Boussinesq method for stress computation and nonlinear methods for primary consolidation.

The foundation bearing soils should be observed by a representative from Golder prior to placing forms or rebar to verify that the bearing soil conditions are as anticipated at the time of this study.

5.2 Lateral Load Resistance

Building foundations must resist lateral loads due to earth pressures, wind, and seismic events. For design purposes, these loads can be restrained simultaneously by:

- Base Friction: An allowable value of 0.35 can be assumed for base friction between the soil or structural fill and spread footings. This value includes a factor of safety of 1.5.
- Passive Resistance on Sides of Shallow Footings: For design purposes, we recommend that the allowable passive pressure be based on a fluid with a density of 250 pcf (includes a factor of safety =1.5) on the sides of buried footings above the water table.

An increase of one third is allowable for transient loads such as wind and seismic influences.

5.3 Slab-on-Grade

We anticipate that slab on grade designs will be developed for the proposed Corrosion Control Facility, and may be utilized with the CMU blower house. A slab-on-grade foundation should be designed using the modulus of subgrade reaction. The modulus of subgrade reaction of the soil depends on the dimensions and stiffness of the slab. The modulus of subgrade reaction for a 1 by 1 foot unit area is defined as k_1. We recommend k_1 = 500 kips per cubic foot (kips/ft3) for the CCF and CMU building. The modulus of subgrade reaction for the full-size slab-on-grade foundations can be approximated using the following relationship from Scott (1981):

$$k_0 = k_1 \left(\frac{B+1}{2B}\right)^2$$

Where B is the effective diameter of the slab's reaction area. For large values of B, the equation can be approximated by:

$$k_0 = 0.25 \times k_1$$

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5.4 Slab Subgrade

Conventional slab-on-grade floors can be supported on a subgrade section as outlined in the Subgrade Perpetration section 6.3, with a minimum embedment depth of 18 inches, on a structural fill section with a minimum thickness of 24 inches. We recommend that interior building slabs be underlain by a capillary break material, consisting of at least four inches of clean, free draining sand and gravel or crushed rock containing less than two percent fines passing the #200 sieve (based on the minus No. 4 sieve fraction) meeting the specifications below in Table 5-2. The base course should be compacted to at least 95 percent of its maximum dry density as determined by ASTM Test Method D 1557.

Table 5-2: Capillary Break Gradation

Sieve Size of diameter (in)	%Passing
1"	100%
No. 4	0%-70%
No. 10	0%-30%
No. 100	0%-5%
No. 200	0%-2%

Vapor transmission through floor slabs in an important consideration in the performance of floor coverings and controlling moisture in structures. Floor slab vapor transmissions can be reduced through the use of suitable vapor retarders such as plastic sheeting placed between the capillary break and the floor slab, and/or specially formulated concrete mixes. Framed floors should also include vapor protection over any areas of bare soils and adequate crawl space ventilation and drainage should be provided. The identification of alternatives to prevent vapor transmission is outside of our expertise. A qualified architect or building envelope consultant can make recommendations for reducing vapor transmission through the slab, based on the building use and slab specification.

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5.5 Additional Design Considerations

5.5.1 Overturning

At the time of this report foundation uplift loads were not provided. Uplift capacity will consist of the weight of the foundation. Conventional methods to meet the required uplift capacity requirements should include a thickened slab-on-grade or a thickened edge slab-on-grade (turndowns). Golder understands that the Corrosion Control Facility (CCF) tower foundation may require additional uplift capacity due to lateral loading from wind and/or seismic forces.

5.5.2 Helical Anchors

Helical anchors consist of a 2 to 3 inch square or round piece of high strength steel that extends to the desired depth. Near the bottom of the anchor, two or three round helixes are welded on to the two inch steel rod. Helical anchors are generally installed using a vehicle that 'screws' the anchor into the ground to the design depth. The helixes allow the anchor to be installed properly and provide the load bearing capacity of the anchor. Anchors can generally produce capacities ranging from 8,000 to 30,000 pounds in glaciated soils. The design shall be in accordance with Chapter 18 of IBC 2012.

Helical anchors would need to be anchored into the underlying glacial till to develop additional uplift capacity. Installing anchors into the till is possible, but could prove difficult due to the cementation of the till and potential for cobbles and boulders. A proof testing program would be required to verify anchor capacity. Helical anchor size and specification is dependent upon the required capacities for the foundation; design calculations can be provided by Golder on a needed basis if required.

5.5.3 Utilities

Utilities that project through the slabs on grade should be designed with either some degree of flexibility or with sleeves. Such design features will help reduce the risk of damage to the utility lines as vertical movements occur.

Backfill for utility lines should consist of on-site material. If the backfill is too dense or dry, swelling may form a mound along the ditch line. If the backfill is too loose or wet, settlement may form a sink along the ditch line. Compaction of utility trench lines should follow the provisions in section 6.2 Utilities.

5.5.4 Permanent Drainage Provisions

Based on the open gradation of the native soils located at the site, footing drains will not be required for shallow foundations. Roof drainage should be collected by a system of gutters and downspouts and either outfall onto splash block dissipators, or be transmitted by pipe to a storm drainage system where the water can drain away without entering the building subgrade.

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6.0 CONSTRUCTION RECOMMENDATIONS

We anticipate the site earthwork for the proposed project will include grading and overexcavating to establish building pad and footing subgrade, installing underground utilities, and connecting to existing utilities.

6.1 Site Preparations and Stripping

Prior to construction of the proposed structures and new facility, all areas should be stripped of all vegetation, debris, and any deleterious soil conditions that might be encountered. In no case should the stripped or grubbed materials be used as structural fill, nor should they be mixed with material to be used as structural fill.

Surface and shallow perched groundwater should be collected and routed to an approved surface water collection and discharge system. Surface water drainage from the site must be controlled during and after construction to avoid erosion and uncontrolled runoff, in accordance with local, state, and federal regulations. Specific recommendations for the surface water management system are beyond the scope of the study presented in this report.

6.2 Erosion Control

Erosion control for the site will include the Best Management Practices (BMPs) incorporated in the civil design drawings and may incorporate the following recommendations:

- Limit exposed cut slopes.
- Route surface water through temporary drainage channels around and away from exposed slopes.
- Use silt fences, straw, and temporary sedimentation ponds to collect and hold eroded material on the site.
- Seeding or planting vegetation on exposed areas where work is completed and no buildings are proposed.
- Retaining existing vegetation to the greatest possible extent.

We recommend that the contractor sequence excavations so as to provide constant positive surface drainage for rainwater and any groundwater seepage that may be encountered. This will require grading slopes, and constructing temporary ditches, sumps and/or berms.

6.3 Earthworks

6.3.1 Subgrade Preparation

Subgrade preparation will consist of cuts into existing fill and undisturbed native soil and placement of structural fill. The subgrade soils should be prepared in accordance with the recommendations in this section to achieve a firm and unyielding condition.

For the building footing excavations, the native sand and gravels should be overexcavated to a depth of at least 3.5 feet below final grade prior to compaction of the native soils. This excavation includes the minimum embedment depth for frost protection of 18 inches and the 2 foot thick structural fill bearing pad. The excavation should extend at least 3.5 feet beyond the edge of foundation footprint.

The site soils will be sensitive to disturbance from construction activities. Foundation subgrades should be maintained in a well compacted state and protected from degradation prior to structural fill. Disturbed or wet areas should be remediated by a method determined suitable, based on the observed field conditions. The options may include drying and recompaction, excavation and replacement of the disturbed soil, placement of a geotextile separation fabric (such as Mirafi 600x or equivalent), chemical stabilization, and/or drainage improvements. Protection measures may include restricted traffic, perimeter drainage ditches, or placement of a protective gravel layer on the sub grade.

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6.3.2 Fill Materials and Placement

We recommend that all fills, native or otherwise, intended to support structures be placed in horizontal lifts not exceeding 8 inches in loose thickness and be compacted to at least 95 percent of the maximum dry density as determined by the Modified Proctor method (ASTM D1557).

The procedure to achieve proper density of a compacted fill depends on the size and type of compacting equipment, the number of passes, thickness of the layer being compacted, and certain soil properties. When the size of the excavation restricts the use of heavy equipment, smaller equipment can be used, but the soil must be placed in lifts thin enough to achieve the required compaction. We recommend that methods of compaction be left to the discretion of the contractor, with compaction testing provided by Golder Associates Inc.

Maximum Lift Thickness:

- On-site native soils or imported granular materials- 8 inches loose

Minimum Compaction Requirements:

- Beneath Building Foundations - The structural fill should be compacted to at least 95 percent of the ASTM D1557 maximum dry density value (modified Proctor value) for the material. The structural fill beneath footings should at a minimum extend laterally at a 1H:1V slope projected down and away from the bottom footing edge.
- Beneath Roadways, Slabs and Pavements - Three feet or deeper below final grade, structural fill should be compacted to at least 90 percent of the ASTM D1557 maximum dry density value for the material. Within three feet or subgrade elevation, the fill should be compacted to at least 95 percent of the ASTM D1557 maximum dry density value for the material.
- Utility Trench Backfill - The fill should generally be compacted to at least 90 percent of the ASTM D1557 maximum dry density value for the material, except within three feet or subgrade elevation, where the fill should be compacted to at least 95 percent or the ASTM D1557 maximum dry density value for the material.
- Non-structural/Landscaped Areas - Firmly compact the soil to prevent excessive settlement and sloughing.

6.3.3 Use of Excavated Soils

In general, organic material, silt, and clay should not be used for structural fill. The glacial till and outwash sands and gravel at the site is considered suitable for reuse as structural fill provided that it has a maximum particle size of less than 8 inches, is near the optimum moisture content, and can achieve specified compaction. Excavated soils used as structural fill should be placed and compacted near the optimum moisture content and in accordance with the compaction requirements presented in Section 6.6.2. If density tests indicate that compaction is not being achieved due to moisture content, the fill should be scarified, and moisture-conditioned to near optimum moisture content, re-compacted, and re-tested, or removed and replaced.

6.3.4 Imported Structural Fill

Imported structural fill should be clean, well graded granular material, a maximum particle size less than 8 inches, free of organics and debris, and should consist of low volume change soils. By our definition, low volume change soils would be cohesive materials having a liquid limit less than 40 and a plasticity index less than 18, or non-cohesive soils with at least 15 percent fines (materials passing the No. 200 U.S. Standard sieve), such as silty gravel or silty sands. Granular soils should be placed at workable moisture contents, generally within 2% of optimum moisture content.

6.3.5 Utility Excavations

Maintaining safe utility excavations is the responsibility of the contractor. The soil and groundwater conditions in the utility excavations may vary across the site. We expect excavations in the site soils to potentially cave. Low to moderate perched groundwater inflow could be encountered at around 4 to 6.5 feet below ground surface based on observations in our exploration test pits. As appropriate, trench shoring or dewatering should be employed by the contractor.

Existing underground utilities to be abandoned should be plugged or removed so they do not provide a conduit for water and cause soil saturation and instability problems.

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7.0 ADDITIONAL SERVICES

As the geotechnical engineer of record, Golder should be retained to provide a review of the draft plans and specifications. The purpose of our review will be to verify that the recommendations presented in this report have been properly interpreted and implemented in the construction drawings and specifications. In addition, the review will allow a discussion of possible changes prior to finalization of the drawings.

Golder should also be retained to observe the geotechnical aspects of the project during construction. The purpose of construction observation services is to verify that the actual conditions encountered during construction are consistent with the conditions assumed for the geotechnical recommendations and design. Our construction observation services will also allow us to more efficiently facilitate changes in the design in the event that subsurface conditions differ from those anticipated prior to the start of construction. Critical aspects of the foundation and earthwork should be observed and tested by Golder. Construction observation and testing services may include but not be limited to foundation subgrade verification, overexcavation observations, and placement and compaction testing of structural fills.

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8.0 CLOSING

This report has been prepared exclusively for the subject property of this report for the use of Gray and Osborne, Inc. We encourage review of this report by bidders and/or contractors as it relates to factual data only (logs of borings, test pits, field observations, etc.). The conclusions and recommendations presented in this report are based on the explorations and observations completed for this study and conversations regarding the proposed site development and are not intended, nor should they be construed to represent, a warranty regarding the proposed development, but are provided to assist in the planning and design process.

Engineering judgment has been applied in interpreting and presenting the results. Variations in subsurface conditions outside of the actual exploration locations are common. Actual conditions encountered during construction may be different from those observed in the explorations. There are possible variations in the subsurface conditions between the test locations and variations over time.

The test pits were excavated in general accordance with locally accepted geotechnical engineering practice, subject to the time limits and financial and physical constraints applicable to the services for this project, to provide information for the areas explored.

The presence or implications of possible surface or subsurface contaminants from any source are outside the terms of reference for this geotechnical study and have not been investigated or addressed herein. Wetland or creek or river impact study, septic field hazard or impact evaluation, creek or river bank erosion, and any other tasks not specifically identified in the SOW are beyond the scope of work for this project.

We trust that the above meets your present requirements. If you have any questions or require additional information, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES INC.

BRIAN M. WILLMAN
36721
EXPIRES: 6/6/2015

Christopher L. Raeburn, PE
Staff Engineer

Brian M. Willman, PhD, PE, GE
Senior Consultant

clr/ajw/bmw

9.0 REFERENCES

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CH2MHill, 2003, Geotechnical Data Report, Meridian Reservoir No. 1 Replacement, Olympia, Washington. Prepared for City of Olympia, Washington.

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Established in 1960, Golder Associates is a global, employee-owned organization that helps clients find sustainable solutions to the challenges of finite resources, energy and water supply and management, waste management, urbanization, and climate change. We provide a wide range of independent consulting, design, and construction services in our specialist areas of earth, environment, and energy. By building strong relationships and meeting the needs of clients, our people have created one of the most trusted professional services organizations in the world.

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DRAFT

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Golder Associates

Engineering Earth's Development, Preserving Earth's Integrity

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Figures

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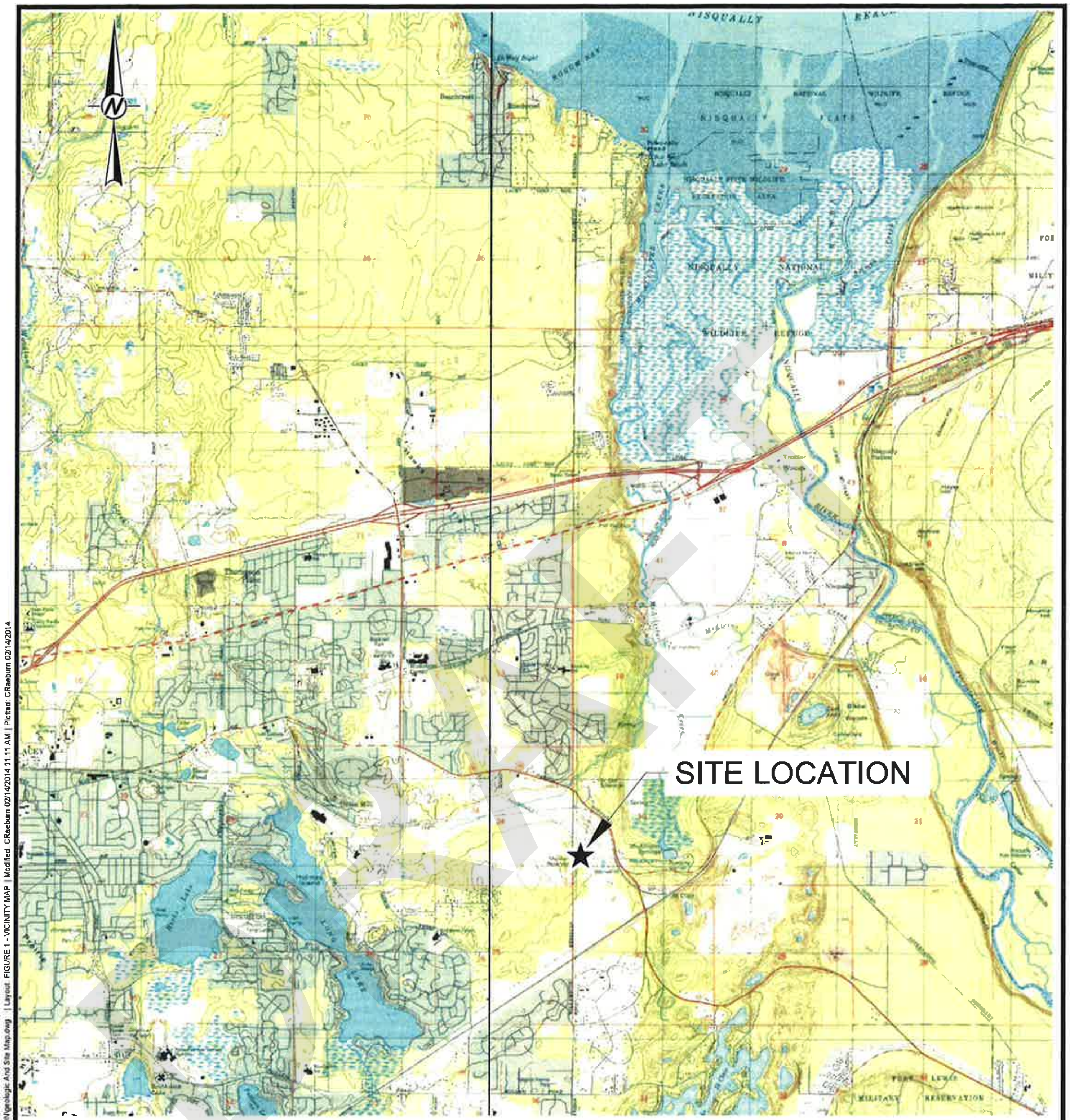


LEGEND

★ APPROXIMATE SITE LOCATION

REFERENCE

1. MAPS PRODUCED BY THE USGS; LACEY AND NISQUALLY, WASHINGTON. http://nationalmap.gov/ustopo/index.html.

0 1/2 1 1 1/2

SCALE MILES

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW

PROJECT

OLYMPIA MERIDIAN RESERVOIR
THURSTON COUNTY, WASHINGTON
GEOTECHNICAL EVALUATION

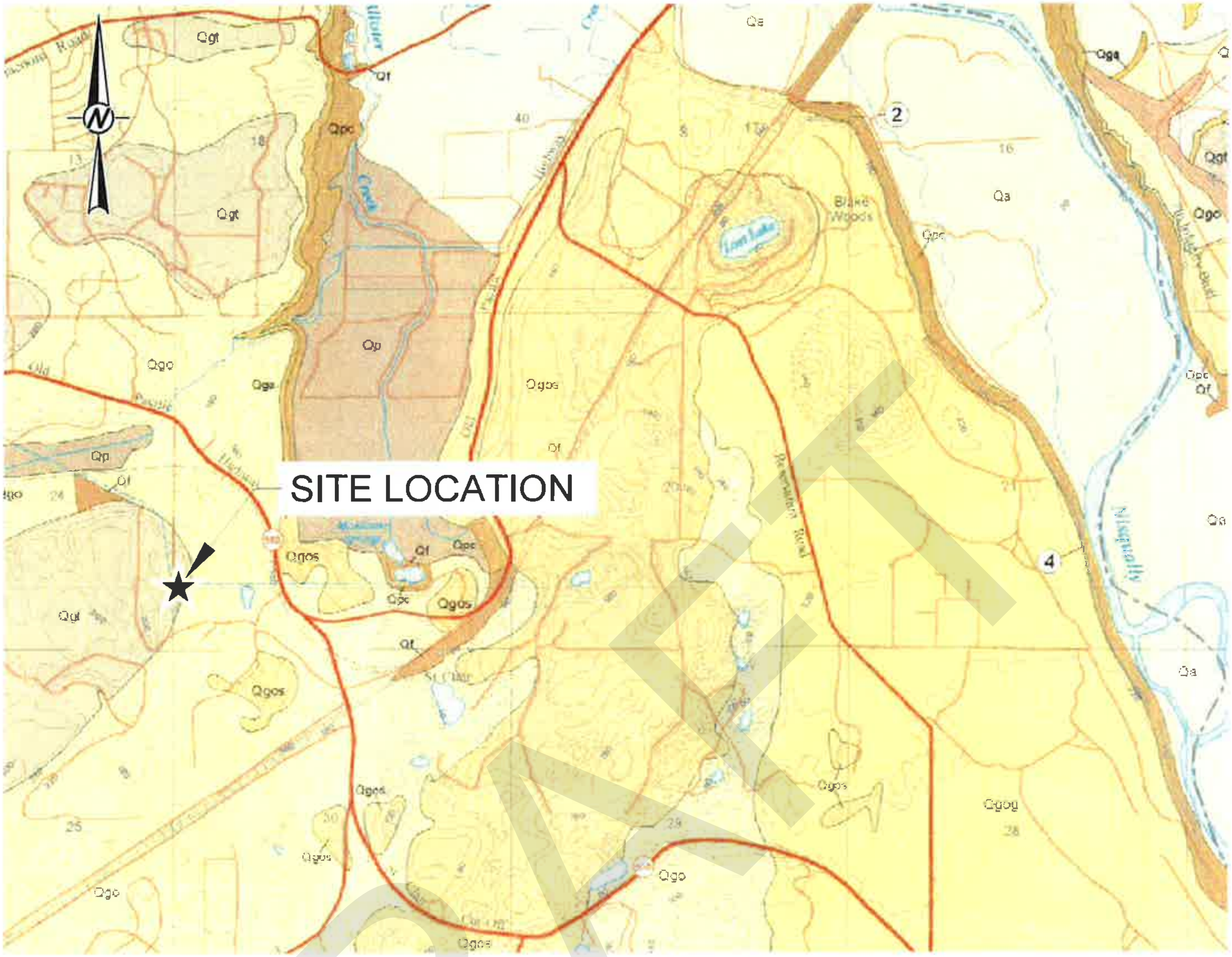
TITLE

VICINITY MAP

PROJECT No.		123-9975501	FILE No. Geologic And Site Map
DESIGN	CLR	1/06/14	SCALE AS SHOWN
CADD	CLR	1/13/14	
CHECK	BMW	2/14/14	**FIGURE 1**
REVIEW	AJW	1/27/14	

Golder Associates

S:\Projects\2013\2013 Geotechnical Projects\Gray & Osborne (123-99755-01)\700_CAD\PRODUCTION\geologic And Site Map.dwg | Layout: FIGURE 1 - VICINITY MAP | Modified: CRaeburn 02/14/2014 11:11 AM | Plotted: CRaeburn 02/14/2014



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LEGEND

Qf **Fill -** Clay, silt, sand, gravel, organic matter, shells, rip-rap, and debris; includes engineered and non engineered fills, shown only where fill placement is extensive, sufficiently thick to be of geotechnical significance, and readily verifiable.

Qgo **Vashon recessional outwash -** Recessional and proglacial stratified, moderately to well-rounded, poorly to moderately sorted outwash sand and gravel of northern or mixed northern and Casacade source, locally containing silt and clay; also contains lacustrine deposits and ice-contact stratified drift. Some areas mapped as unit Qgo may intead be advance outwash (unit Qga), as it is difficult to tell the difference between the two without the presence of an intervening till.

Qgos **Latest Vashon recessional sand and minor silt -** Moderately well-sorted, moderately to well-rounced, fine- to medium-grained sand with minor silt; noncohesive and highly permeable; thickness inferred from wells reaches up to 100 ft; deposited in and around the margins of glacial lakes; surrounds numerous steep-walled lakes and depressions (kettles), evidence tha this unit was largely deposited during deglaciation when there was stagnant ice occupying much of the southern Puget Lowland.

Qgt **Vashon till -** Unstratified and, in most exposures, highly compacted mixture of clay, silt, sand, and gravel deposited directly by glacier ice; gray where fresh and light yellowish brown where oxidized; unsorted and, in most exposures, of very low permeability; most commonly matrix-supported but may be clast-supported; matrix generally has a more gritty feel than outwash sands when rubbed between fingers, due to being more angular than water-worked sediments; cobbles and boulders commonly faceted and (or) striated; ranges in thickness from wispy, discontinuous layers less than 1 in. to more than 30 ft thick; thickness of 2 to 10 ft are most common; mapped till commonly includes outwash clay, silty, sand, gravel, or ablation till tha is too thin to substantially mask the underlying, rolling till plain; erratic boulders are commonly associates with till plains but may also occur as lag deposits where the underlying deposits have been modified by meltwater; typically, wealkly developed modern soil has formed on the cap of loose gravel, but the underlying till is unweathered; local textual features in the till include flow banding and apophyses commonly extending 10 to 15 ft downward into underlying sand and gravel that are oriented transverse to ice flow direction.

REFERENCE

1. WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES. *Geologic Map of the Nisqually 7.5-minute Quadrangle, Thurston and Pierce Counties, Washington.* Timothy J. Walsh, Robert L. Logan, Michael Polenz, and Henry W. Schasse, 2003.

0 2 4 6
SCALE MILES

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW

PROJECT
OLYMPIA MERIDIAN RESERVOIR
THURSTON COUNTY, WASHINGTON
GEOTECHNICAL EVALUATION

TITLE
GEOLOGIC MAP

Golder Associates

PROJECT No.		123-9975501	FILE No.	Geologic And Site Map
DESIGN	CLR	1/06/14	SCALE	AS SHOWN
CADD	CLR	1/13/14		
CHECK	BMW	2/14/14	**FIGURE 2**	
REVIEW	AJW	1/27/14		

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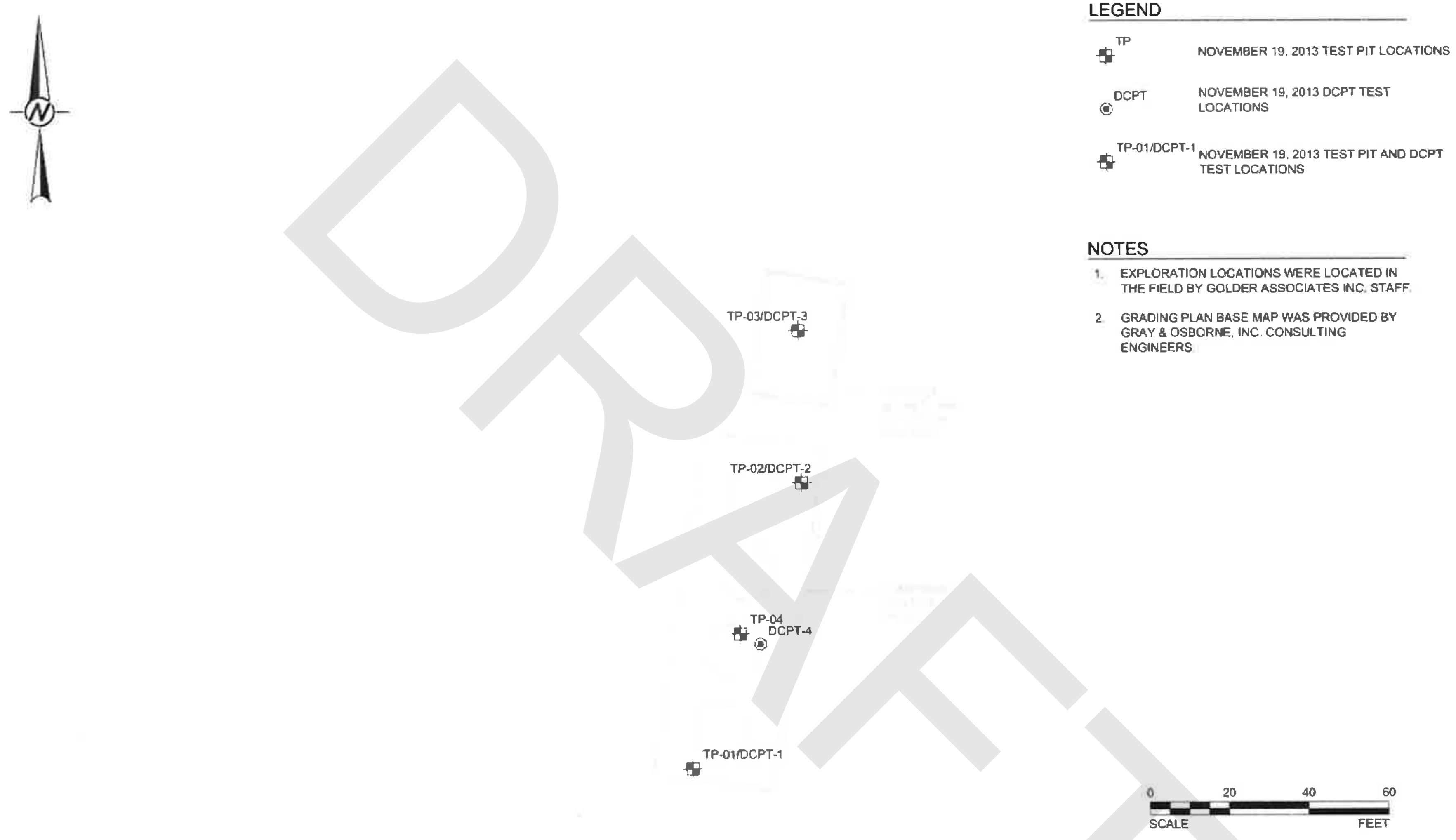

NOTES

1. EXPLORATION LOCATIONS WERE LOCATED IN THE FIELD BY GOLDER ASSOCIATES INC. STAFF.
2. GRADING PLAN BASE MAP WAS PROVIDED BY GRAY & OSBORNE, INC. CONSULTING ENGINEERS.

PROJECT

OLYMPIA MERIDIAN RESERVOIR
THURSTON COUNTY, WASHINGTON
GEOTECHNICAL EVALUATION

TITLE

EXPLORATION LOCATION MAP

Golder Associates

PROJECT No		123-9975501
DESIGN	CLR	11/20/13
CADD	CLR	11/20/13
CHECK	BMW	2/14/14
REVIEW	AJW	1/27/14

FILE No 123-9975501 EXPLORATION SITE MAP

SCALE AS SHOWN

FIGURE

FIGURE 3

Appendix A

TEST PIT AND DCPT RECORDS

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RECORD OF TEST PIT TP-01

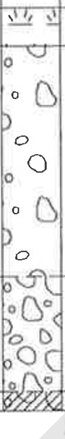
SHEET 1 of 1

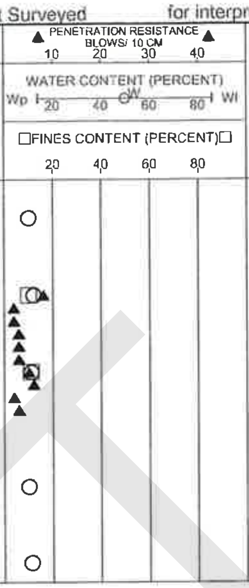
CLIENT: Gray and Osborne
PROJECT: Olympia Corrosion Control Facility
PROJECT NUMBER: 1239975501

LOCATION: Olympia, WA
EXCAVATION DATE: 11/19/2013
EQUIPMENT: JOHN DEERE 200LC

DATUM: MSL
AZIMUTH: N/A
COORDINATES: Not Surveyed

ELEVATION: 293.0
NOTES: See DCPT TP-01 for interpreted N-values





DEPTH ()	SOIL PROFILE DESCRIPTION	USCS	ELEV. / DEPTH (ft)	SAMPLES NUMBER	SAMPLES TYPE	NOTES WATER LEVELS
0	(SP) fine to coarse POORLY GRADED SAND, non plastic, some silt; dark gray; moist, very loose to loose (Topsoil)	SP	292.0 1.0	1	GB	No Seepage Observed
5	(SP) gravelly fine to coarse POORLY GRADED SAND, non plastic, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; gray; moist, compact; Small tree root organics at 5 ft (Fill)	SP	286.0 7.0	2 3	GB GB	5-10ft BGS, 1 to 2 ft of caving into wall observed
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; brown, organic; moist, loose (Glacial Outwash)	GP	283.0 10.0	4	GB	
10	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, some cobbles, some silt; gray; moist, very dense (TILL)	GP	282.5 10.5	5	GB	

Bottom of test pit at 10.5 feet.

DRAFT

TEST PIT PHOTOS:

EXCAVATION CONTRACTOR: Clearcreek Contractors
OPERATOR: Tom Dodds

LOGGED: C. RAEBURN
CHECKED: J. Gerst
DATE: 12/04/2013

Golder Associates

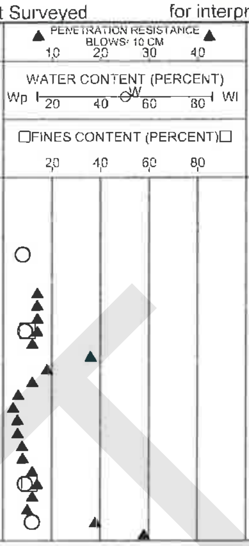
RECORD OF TEST PIT TP-02

SHEET 1 of 1

CLIENT: Gray and Osborne
PROJECT: Olympia Corrosion Control Facility
PROJECT NUMBER: 1239975501
LOCATION: Olympia, WA
EXCAVATION DATE: 11/19/2013
EQUIPMENT: JOHN DEERE 200LC
DATUM: MSL
AZIMUTH: N/A
COORDINATES: Not Surveyed
ELEVATION: 292.0
NOTES: See DCPT TP-02 for interpreted N-values

DEPTH ()	SOIL PROFILE: DESCRIPTION	USCS	ELEV. / DEPTH (ft)	SAMPLES: NUMBER	SAMPLES: TYPE	NOTES WATER LEVELS
0	(SP) gravelly fine to coarse POORLY GRADED SAND, non plastic, some silt; dark gray; moist, compact (Topsoil)	SP	291.5 0.5			
	(SP) gravelly fine to coarse POORLY GRADED SAND, non plastic, cobbles <4 in, sub-angular to sub-rounded gravel, some silt; brown; moist, compact (Fill)	SP	289.0 3.0	1	GB	
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, low plasticity, cobbles <6 in, sub-angular to sub-rounded gravel, some silt; brown, orange; moist, very loose to compact (Glacial Outwash)	GP	283.0 9.0	2	GB	
5						5.0 ft, Very slow seepage
				3	GB	
				4	GB	
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, some silt; gray; moist, very dense (TILL)	GP	282.5 9.5			

Bottom of test pit at 9.5 feet.



TEST PIT PHOTOS:

EXCAVATION CONTRACTOR: Clearcreek Contractors
OPERATOR: Tom Dodds

LOGGED: C. RAEBURN
CHECKED: J. Gerst
DATE: 12/04/2013

Golder Associates

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RECORD OF TEST PIT TP-03

SHEET 1 of 1

CLIENT: Gray and Osborne
PROJECT: Olympia Corrosion Control Facility
PROJECT NUMBER: 1239975501

LOCATION: Olympia, WA
EXCAVATION DATE: 11/19/2013
EQUIPMENT: JOHN DEERE 200LC

DATUM: MSL
AZIMUTH: N/A
COORDINATES: Not Surveyed

ELEVATION: 292.0
NOTES: See DCPT TP-03 for interpreted N-values

DEPTH ()	SOIL PROFILE: DESCRIPTION	USCS	GRAPHIC LOG	ELEV. / DEPTH (ft)	SAMPLES: NUMBER	SAMPLES: TYPE	▲ PENETRATION RESISTANCE BLOWS/ 10 CM ▲ (10, 20, 30, 40); WATER CONTENT (PERCENT) Wp ├ 20 40 ○W 60 80 ┤ Wl; ☐FINES CONTENT (PERCENT)☐ (20, 40, 60, 80)	NOTES WATER LEVELS
0	(SP) gravelly fine to coarse POORLY GRADED SAND, non plastic, some silt; dark gray; moist, compact (Topsoil/Sod)	SP		291.5 0.5				
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; gray; moist, very dense (TILL)	GP					○	
					1	GB		
				288.5 3.5	2	GB	○ ▲ ▲	
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, some silt; brown; moist, compact (Glacial Outwash)	GP						3.5 ft, Very slow seepage
5				286.0 6.0	3	GB	○☐	
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; brown; moist, loose to compact (Glacial Outwash)	GP			4	GB	○	
				282.5 9.5	5	GB	○☐	

Bottom of test pit at 9.5 feet.

DRAFT

TEST PIT PHOTOS:

TEST PIT RECORD GINT STD US.GPJ GINT STD US LAB.GDT 1/29/14

EXCAVATION CONTRACTOR: Clearcreek Contractors
OPERATOR: Tom Dodds

LOGGED: C. RAEBURN
CHECKED: J. Gerst
DATE: 12/04/2013

Golder Associates

RECORD OF TEST PIT TP-04

SHEET 1 of 1

CLIENT: Gray and Osborne
PROJECT: Olympia Corrosion Control Facility
PROJECT NUMBER: 1239975501

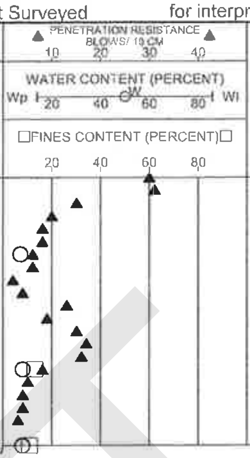
LOCATION: Olympia, WA
EXCAVATION DATE: 11/19/2013
EQUIPMENT: JOHN DEERE 200LC

DATUM: MSL
AZIMUTH: N/A
COORDINATES: Not Surveyed

ELEVATION: 293.0
NOTES: See DCPT TP-04 for interpreted N-values

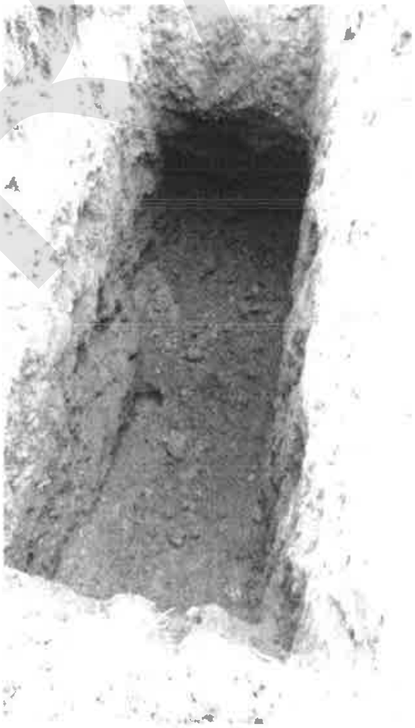
DEPTH ()	SOIL PROFILE DESCRIPTION	USCS	ELEV. / DEPTH (ft)	SAMPLES NUMBER	SAMPLES TYPE	NOTES WATER LEVELS
0	(SP) gravelly fine to coarse POORLY GRADED SAND, non plastic, some silt; dark gray; moist, compact (Topsoil)	SP	292.5 0.5			Concrete chunk
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; gray; moist, loose to compact (Fill)	GP	291.0 2.0	1	GB	
5	(GP) sandy fine to coarse POORLY GRADED GRAVEL, low plasticity, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; brown; moist, loose to compact (Glacial Outwash)	GP	286.5 6.5	2	GB	5.0 ft, Very slow seepage
	(GP) sandy fine to coarse POORLY GRADED GRAVEL, non plastic, sub-angular to sub-rounded gravel, cobbles <6 in, some silt; brown; moist, loose to compact; End of pit at 7' due to exposed utility pipe (blue 8" PVC) (Glacial Outwash)	GP	286.0 7.0	3	GB	PVC Pipe at SW corner

GRAPHIC LOG



Bottom of test pit at 7.0 feet.

TEST PIT PHOTOS:



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EXCAVATION CONTRACTOR: Clearcreek Contractors
OPERATOR: Tom Dodds

LOGGED: C. RAEBURN
CHECKED: J. Gerst
DATE: 12/04/2013

Golder Associates

WILDCAT DYNAMIC CONE LOG

Page 1 of 1

Golder Associates
9 Monroe Parkway, Suite 270
Lake Oswego, OR 97035

PROJECT NUMBER: 123-9975501
DATE STARTED: 11-19-2013
DATE COMPLETED: 11-19-2013

HOLE #: TP-01
CREW: CLR
PROJECT: Olympia CCF
ADDRESS: Seaton Ct. SE
LOCATION: Olympia, WA

SURFACE ELEVATION: 3' bgs (290msl)
WATER ON COMPLETION: None
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm^2	GRAPH OF CONE RESISTANCE	N'	TESTED CONSISTENCY	
			0 50 100 150		SAND & SILT	CLAY
-	8	35.5	••••••••••	10	LOOSE	STIFF
-	2	8.9	••	2	VERY LOOSE	SOFT
- 1 ft	2	8.9	••	2	VERY LOOSE	SOFT
-	3	13.3	•••	3	VERY LOOSE	SOFT
-	3	13.3	•••	3	VERY LOOSE	SOFT
- 2 ft	3	13.3	•••	3	VERY LOOSE	SOFT
-	5	22.2	••••••	6	LOOSE	MEDIUM STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
- 3 ft	2	8.9	••	2	VERY LOOSE	SOFT
- 1 m	3	13.3	•••	3	VERY LOOSE	SOFT
-						
- 4 ft						
-						
-						
- 5 ft						
-						
-						
- 6 ft						
-						
- 2 m						
- 7 ft						
-						
-						
- 8 ft						
-						
-						
- 9 ft						
-						
-						
- 3 m 10 ft						
-						
-						
-						
- 11 ft						
-						
-						
- 12 ft						
-						
-						
- 4 m 13 ft						

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WILDCAT DYNAMIC CONE LOG

Page 1 of 1

Golder Associates
9 Monroe Parkway, Suite 270
Lake Oswego, OR 97035

PROJECT NUMBER: 123-9975501
DATE STARTED: 11-19-2013
DATE COMPLETED: 11-19-2013

HOLE #: TP-02
CREW: CLR
PROJECT: Olympia CCF
ADDRESS: Seaton Ct. SE
LOCATION: Olympia, WA

SURFACE ELEVATION: 3ft bgs (289msl)
WATER ON COMPLETION: None
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm^2	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY SAND & SILT	CLAY
-	7	31.1	•••••••••	8	LOOSE	MEDIUM STIFF
-	7	31.1	•••••••••	8	LOOSE	MEDIUM STIFF
- 1 ft	7	31.1	•••••••••	8	LOOSE	MEDIUM STIFF
-	7	31.1	•••••••••	8	LOOSE	MEDIUM STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
- 2 ft	18	79.9	•••••••••••••••••••••••	22	MEDIUM DENSE	VERY STIFF
-	9	40.0	•••••••••••	11	MEDIUM DENSE	STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
- 3 ft	3	13.3	•••	3	VERY LOOSE	SOFT
- 1 m	2	8.9	••	2	VERY LOOSE	SOFT
-	3	11.6	•••	3	VERY LOOSE	SOFT
- 4 ft	3	11.6	•••	3	VERY LOOSE	SOFT
-	4	15.4	••••	4	VERY LOOSE	SOFT
-	4	15.4	••••	4	VERY LOOSE	SOFT
- 5 ft	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
-	7	27.0	•••••••	7	LOOSE	MEDIUM STIFF
-	6	23.2	••••••	6	LOOSE	MEDIUM STIFF
- 6 ft	5	19.3	•••••	5	LOOSE	MEDIUM STIFF
-	19	73.3	•••••••••••••••••••••	20	MEDIUM DENSE	VERY STIFF
- 2 m	29	111.9	••••••••••••••••••••••••••••••••	-	DENSE	HARD
- 7 ft						
-						
-						
- 8 ft						
-						
-						
- 9 ft						
-						
-						
- 3 m 10 ft						
-						
-						
-						
- 11 ft						
-						
-						
- 12 ft						
-						
-						
- 4 m 13 ft						

DRAFT

WILDCAT.XLS

WILDCAT DYNAMIC CONE LOG

Golder Associates
9 Monroe Parkway, Suite 270
Lake Oswego, OR 97035

PROJECT NUMBER: 123-9975501
DATE STARTED: 11-19-2013
DATE COMPLETED: 11-19-2013

HOLE #: TP-03
CREW: CLR
PROJECT: Olympia CCF
ADDRESS: Seaton Ct. SE
LOCATION: Olympia, WA

SURFACE ELEVATION: 3ft bgs (289msl)
WATER ON COMPLETION: None
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE 0 50 100 150	N'	TESTED CONSISTENCY SAND & SILT	TESTED CONSISTENCY CLAY
-	26	115.4	•••••••••••••••••••••••••••••••••••	-	DENSE	HARD
-	30	133.2	•••	-	DENSE	HARD
- 1 ft						
-						
-						
- 2 ft						
-						
-						
- 3 ft						
- 1 m						
-						
- 4 ft						
-						
-						
- 5 ft						
-						
-						
- 6 ft						
-						
- 2 m						
- 7 ft						
-						
-						
- 8 ft						
-						
-						
- 9 ft						
-						
-						
- 3 m 10 ft						
-						
-						
-						
- 11 ft						
-						
-						
- 12 ft						
-						
-						
- 4 m 13 ft						

DRAFT

WILDCAT DYNAMIC CONE LOG

Page 1 of 1

Golder Associates
9 Monroe Parkway, Suite 270
Lake Oswego, OR 97035

PROJECT NUMBER: 123-9975501
DATE STARTED: 11-19-2013
DATE COMPLETED: 11-19-2013

HOLE #: TP-04
CREW: CLR
PROJECT: Olympia CCF
ADDRESS: Seaton Ct. SE
LOCATION: Olympia, WA

SURFACE ELEVATION: 293msl
WATER ON COMPLETION: None
HAMMER WEIGHT: 35 lbs.
CONE AREA: 10 sq. cm

DRAFT

DEPTH	BLOWS PER 10 cm	RESISTANCE Kg/cm²	GRAPH OF CONE RESISTANCE	N'	TESTED CONSISTENCY	
			0 50 100 150		SAND & SILT	CLAY
-	30	133.2	••••••••••••••••••••••••••••••••••••••	-	DENSE	HARD
-	31	137.6	•••••••••••••••••••••••••••••••••••••••	-	DENSE	HARD
- 1 ft	15	66.6	•••••••••••••••••••	19	MEDIUM DENSE	VERY STIFF
-	10	44.4	••••••••••••	12	MEDIUM DENSE	STIFF
-	8	35.5	••••••••••	10	LOOSE	STIFF
- 2 ft	8	35.5	••••••••••	10	LOOSE	STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
-	6	26.6	•••••••	7	LOOSE	MEDIUM STIFF
- 3 ft	2	8.9	••	2	VERY LOOSE	SOFT
- 1 m	4	17.8	•••••	5	LOOSE	MEDIUM STIFF
-	13	50.2	••••••••••••••	14	MEDIUM DENSE	STIFF
- 4 ft	9	34.7	••••••••••	9	LOOSE	STIFF
-	15	57.9	••••••••••••••••	16	MEDIUM DENSE	VERY STIFF
-	17	65.6	•••••••••••••••••••	18	MEDIUM DENSE	VERY STIFF
- 5 ft	16	61.8	•••••••••••••••••	17	MEDIUM DENSE	VERY STIFF
-	8	30.9	••••••••	8	LOOSE	MEDIUM STIFF
-	5	19.3	•••••	5	LOOSE	MEDIUM STIFF
- 6 ft	4	15.4	••••	4	VERY LOOSE	SOFT
-	4	15.4	••••	4	VERY LOOSE	SOFT
- 2 m	3	11.6	•••	3	VERY LOOSE	SOFT
- 7 ft						
-						
-						
- 8 ft						
-						
-						
- 9 ft						
-						
-						
- 3 m 10 ft						
-						
-						
-						
- 11 ft						
-						
-						
- 12 ft						
-						
-						
- 4 m 13 ft						

Appendix B

LABORATORY TEST RESULTS

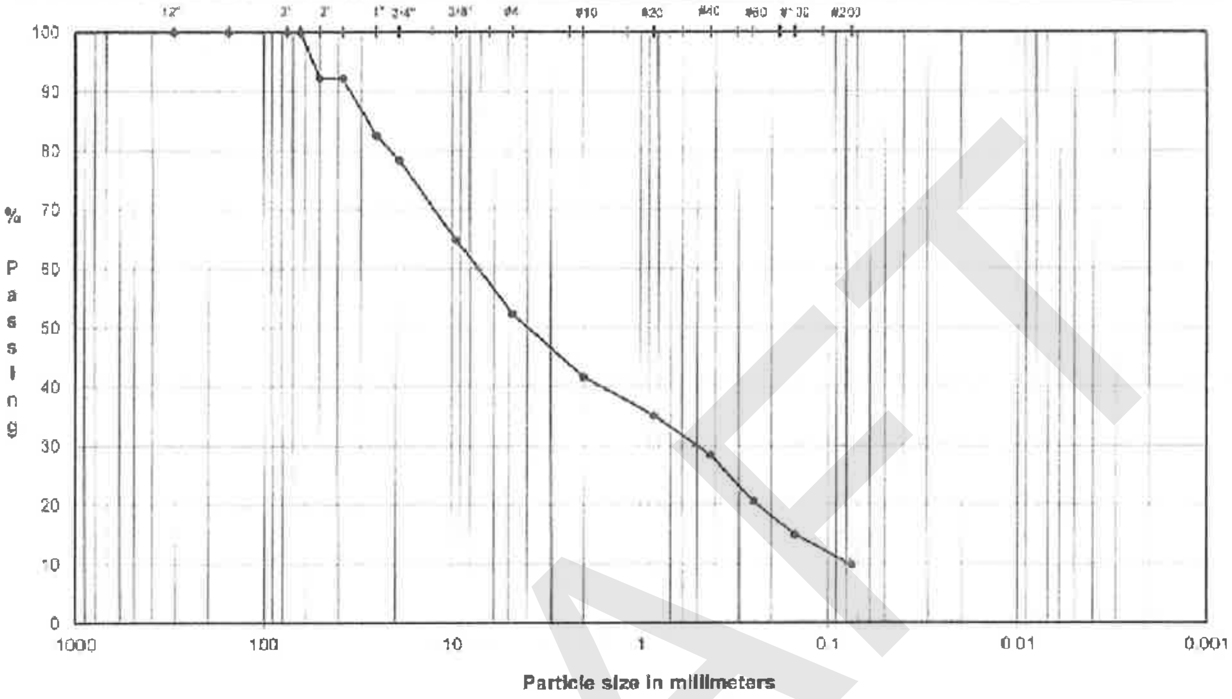
DRAFT

12/4/13 123-99755-01.001

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: **G&O / Olympia Meridian Geotech / WA**
SAMPLE ID: **TP-01** **S-2** Depth: **3ft**
TYPE: -



COBBLES	GRAVEL		SAND			FINES
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

U.S. Standard Sieves Sizes and Numbers

	Particle Size (mm)	% Passing	Particle Size Classification	Particle Size Percentage
12.0"	304.8	100.0	Cobbles	0.0
6.0"	154.2	100.0		
3.0"	75	100.0		
2.5"	63.5	100.0	Coarse Gravel	21.6
2.0"	50	92.3		
1.5"	37.5	92.3		
1.0"	25	82.6		
0.75"	19	78.4		
0.375"	9.5	65.0	Fine Gravel	26.1
#4	4.75	52.3		
#10	2.00	41.7	Coarse Sand	10.6
#20	0.85	35.1	Medium Sand	13.5
#40	0.43	28.4		
#60	0.25	20.6	Fine Sand	18.6
#100	0.15	14.9		
#200	0.075	9.8		
			Fines	9.8

Moisture Content
11.50

D_{60}= 7.23	D_{30}= 0.50	D_{10}= 0.08
Cu = D60/D10 =	93.5	> 6
Cc = D30^2/(D10*D60) =	0.5	< 1

DESCRIPTION: SAND and GRAVEL
some silt

USCS: SP

TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	

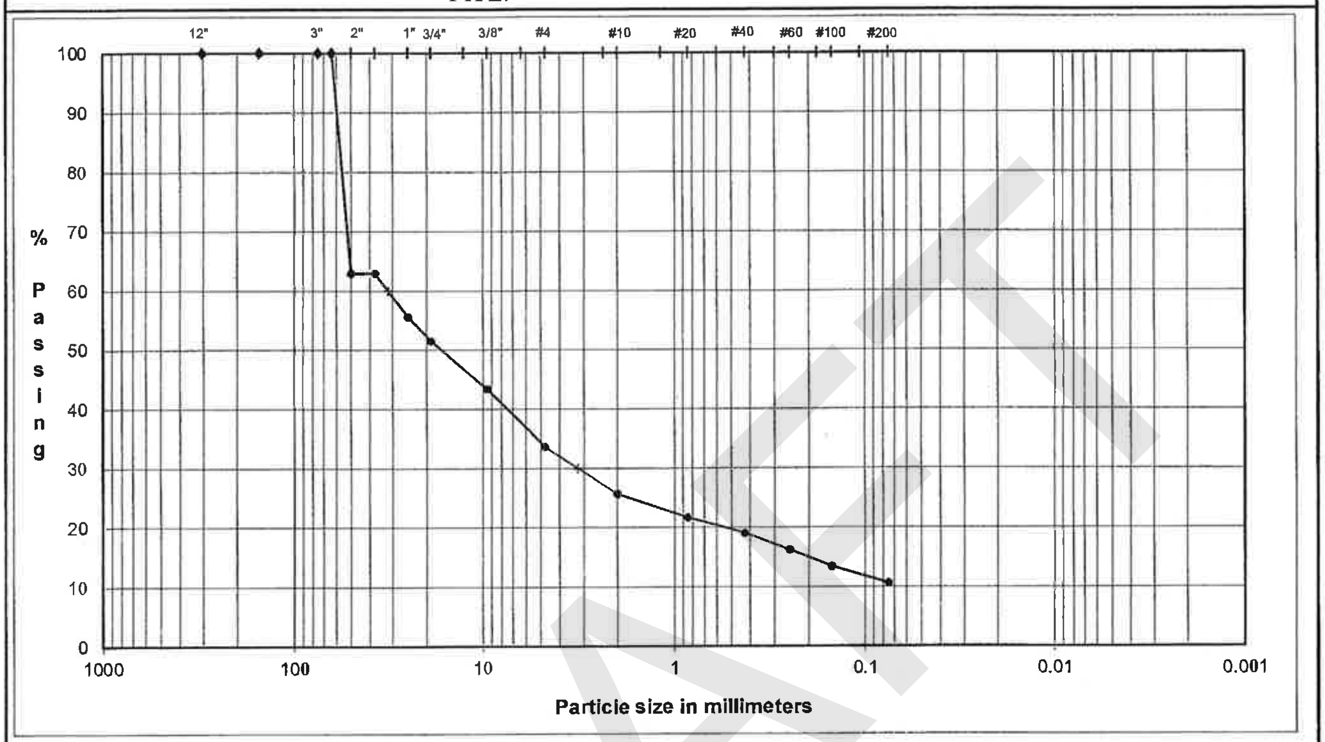
DRAFT

12/4/13 123-99755-01.001

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: **G&O / Olympia Meridian Geotech / WA**
SAMPLE ID: **TP-01** **S-3** Depth: **5ft**
TYPE: -



COBBLES	GRAVEL		SAND			FINES
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

U.S. Standard Sieves Sizes and Numbers	Particle Size (mm)	% Passing	Particle Size Classification	Particle Size Percentage
12.0"	304.8	**100.0**	Cobbles	**0.0**
6.0"	154.2	**100.0**		
3.0"	75	**100.0**		
2.5"	63.5	**100.0**	Coarse Gravel	**48.5**
2.0"	50	**63.0**		
1.5"	37.5	**63.0**		
1.0"	25	**55.6**		
0.75"	19	**51.5**		
0.375"	9.5	**43.4**	Fine Gravel	**17.9**
#4	4.75	**33.6**		
#10	2.00	**25.6**	Coarse Sand	**8.0**
#20	0.85	**21.6**	Medium Sand	**6.6**
#40	0.43	**19.0**		
#60	0.25	**16.2**	Fine Sand	**8.4**
#100	0.15	**13.4**		
#200	0.075	**10.6**		
			Fines	**10.6**

Moisture Content
10.66

D_{60}= 31.83	D_{30}= 3.21	D_{10}= #N/A
Cu = D60/D10 =	**#N/A**	#N/A
Cc = D30^2/(D10*D60) =	**#N/A**	#N/A

DESCRIPTION: sandy GRAVEL
some silt

USCS: GP

TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	

DRAFT

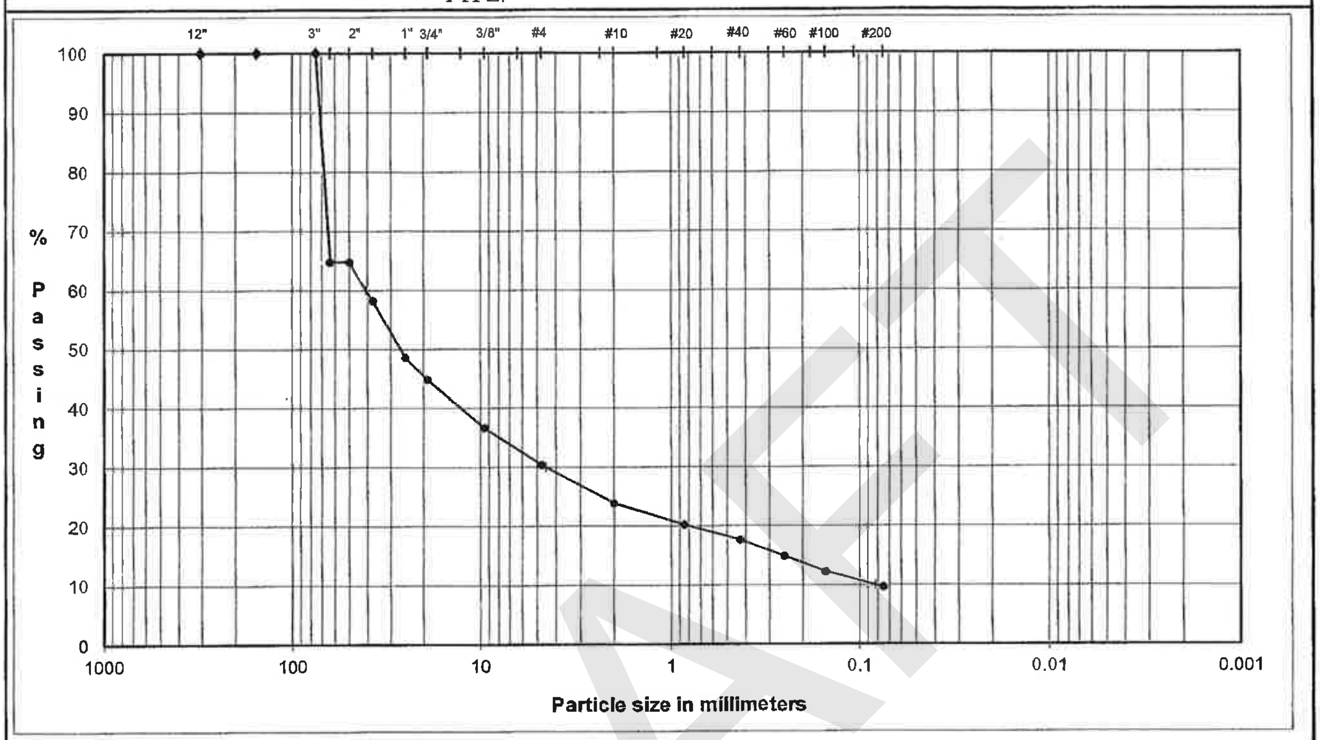
12/4/13

123-99755-01.001

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: **G&O / Olympia Meridian Geotech / WA**
SAMPLE ID: **TP-02** **S-2** Depth: **4ft**
TYPE: -



	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay
COBBLES	GRAVEL		SAND			FINES

U.S. Standard Sieves Sizes and Numbers	Particle Size (mm)	% Passing	Particle Size Classification	Percentage
12.0"	304.8	100.0	Cobbles	0.0
6.0"	154.2	100.0		
3.0"	75	100.0		
2.5"	63.5	64.8	Coarse Gravel	55.2
2.0"	50	64.8		
1.5"	37.5	58.2		
1.0"	25	48.5		
0.75"	19	44.8		
0.375"	9.5	36.6	Fine Gravel	14.4
#4	4.75	30.4		
#10	2.00	23.9	Coarse Sand	6.5
#20	0.85	20.2	Medium Sand	6.3
#40	0.43	17.6		
#60	0.25	14.9	Fine Sand	8.0
#100	0.15	12.2		
#200	0.075	9.7		
			Fines	9.7

Moisture Content: 9.22

D_{60}= 40.54	D_{30}= 4.49	D_{10}= 0.08
Cu = D60/D10 =	492.8	> 4
Cc = D30^2/(D10*D60) =	6.1	> 3

DESCRIPTION: sandy GRAVEL
some silt

USCS: GP

TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	

DRAFT

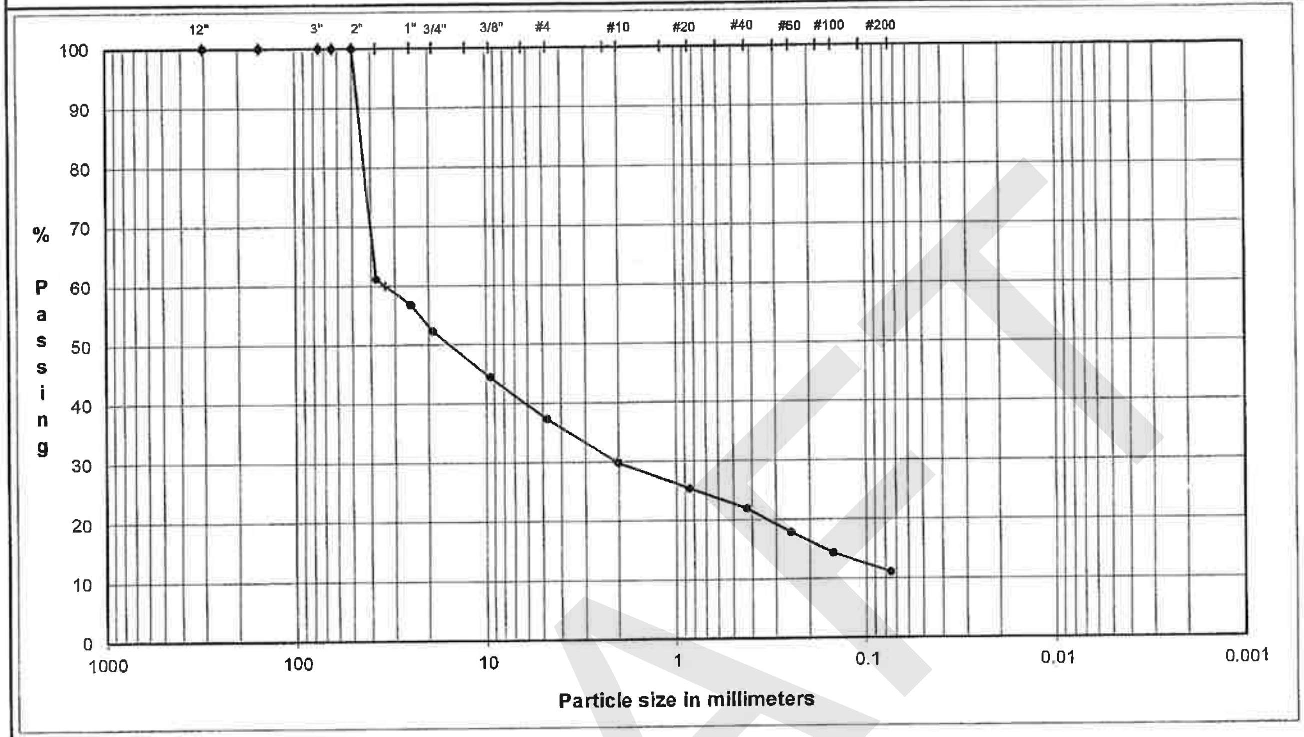
12/4/13

123-99755-01.001

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME:	G&O / Olympia Meridian Geotech / WA			
SAMPLE ID:	TP-02	S-3	Depth:	8ft
TYPE:	-			



	GRAVEL		SAND			FINES
COBBLES	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

U.S. Standard Sieves Sizes and Numbers

	Particle Size (mm)	% Passing	Particle Size Classification	Percentage
12.0"	304.8	100.0	Cobbles	0.0
6.0"	154.2	100.0		
3.0"	75	100.0		
2.5"	63.5	100.0	Coarse Gravel	47.7
2.0"	50	100.0		
1.5"	37.5	61.2		
1.0"	25	56.8		
0.75"	19	52.3		
0.375"	9.5	44.5	Fine Gravel	15.0
#4	4.75	37.3		
#10	2.00	29.8	Coarse Sand	7.6
#20	0.85	25.4	Medium Sand	7.9
#40	0.43	21.9		
#60	0.25	17.9	Fine Sand	10.8
#100	0.15	14.4		
#200	0.075	11.1		
			Fines	11.1

Moisture Content

9.21

D_{60}= 33.61	D_{30}= 2.06	D_{10}= #N/A

Cu = D60/D10 =	#N/A	#N/A
Cc = D30^2/(D10*D60) =	#N/A	#N/A

DESCRIPTION: sandy GRAVEL
some silt

USCS: GP

TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	

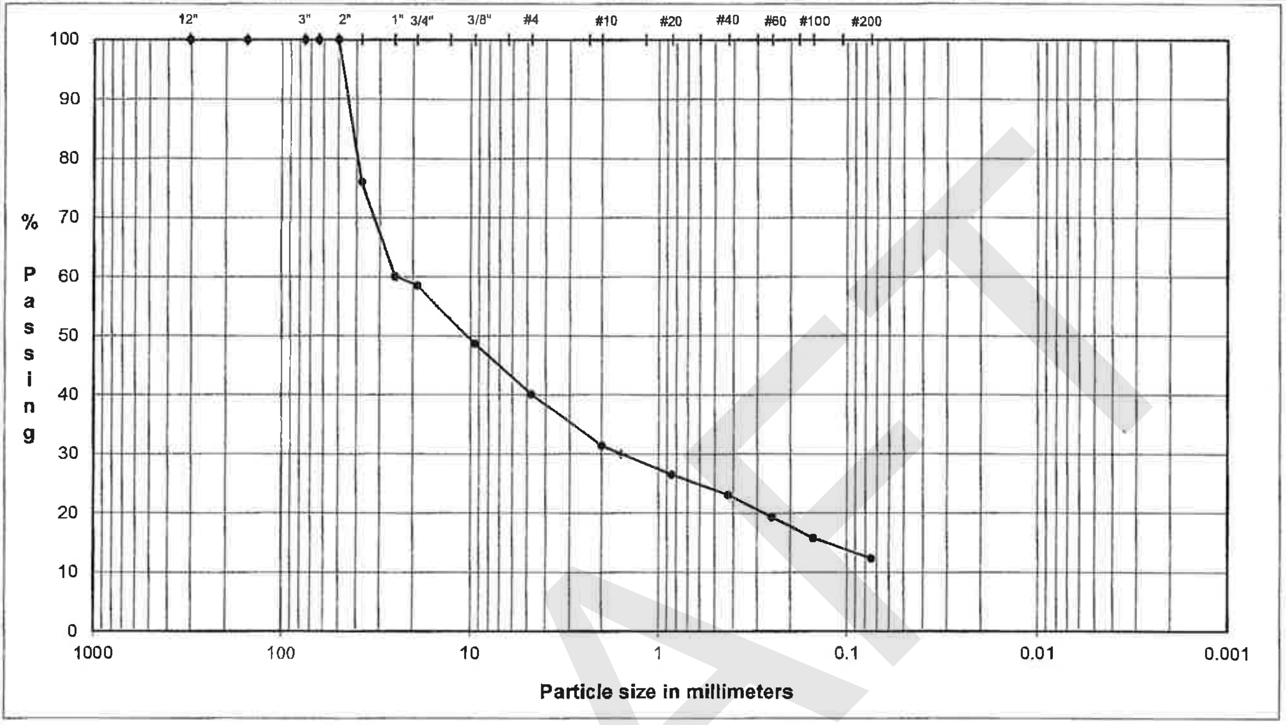
DRAFT

12/4/13 123-99755-01.001

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: G&O / Olympia Meridian Geotech / WA
SAMPLE ID: TP-03 S-3 Depth: 5.5ft
TYPE: -



	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay
COBBLES	GRAVEL		SAND			FINES

U.S. Standard Sieves Sizes and Numbers	Particle Size (mm)	% Passing	Particle Size Classification	Percentage
12.0"	304.8	100.0	Cobbles	0.0
6.0"	154.2	100.0		
3.0"	75	100.0		
2.5"	63.5	100.0	Coarse Gravel	41.5
2.0"	50	100.0		
1.5"	37.5	76.1		
1.0"	25	60.1		
0.75"	19	58.5		
0.375"	9.5	48.7	Fine Gravel	18.4
#4	4.75	40.1		
#10	2.00	31.4	Coarse Sand	8.7
#20	0.85	26.5	Medium Sand	8.3
#40	0.43	23.1		
#60	0.25	19.3	Fine Sand	10.7
#100	0.15	15.8		
#200	0.075	12.4		
			Fines	12.4

Moisture Content
10.61

D_{60}= 24.62	D_{30}= 1.57	D_{10}= #N/A
Cu = D60/D10 =	#N/A	#N/A
Cc = D30^2/(D10*D60) =	#N/A	#N/A

DESCRIPTION: sandy GRAVEL
some silt

USCS: GP

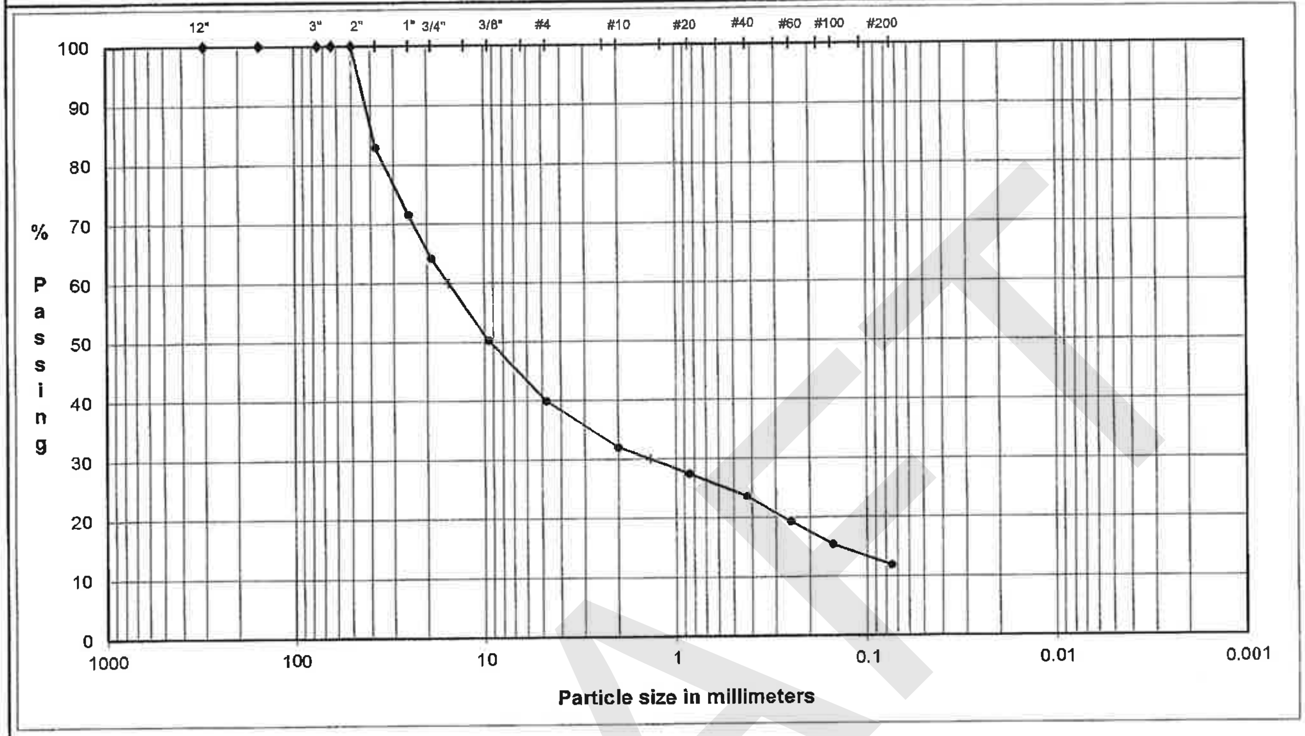
TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	BL

DRAFT

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: **G&O / Olympia Meridian Geotech / WA**
SAMPLE ID: **TP-03** **S-5** Depth: **9.5ft**
TYPE: -



COBBLES	GRAVEL		SAND			FINES
	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay

U.S. Standard Sieves Sizes and Numbers

	Particle Size (mm)	% Passing	Particle Size Classification	Particle Size Percentage
12.0"	304.8	**100.0**	Cobbles	**0.0**
6.0"	154.2	**100.0**		
3.0"	75	**100.0**		
2.5"	63.5	**100.0**	Coarse Gravel	**35.8**
2.0"	50	**100.0**		
1.5"	37.5	**82.9**		
1.0"	25	**71.5**		
0.75"	19	**64.2**		
0.375"	9.5	**50.3**	Fine Gravel	**24.3**
#4	4.75	**39.9**		
#10	2.00	**32.0**	Coarse Sand	**7.9**
#20	0.85	**27.5**	Medium Sand	**8.5**
#40	0.43	**23.5**		
#60	0.25	**19.2**	Fine Sand	**11.7**
#100	0.15	**15.4**		
#200	0.075	**11.9**		
			Fines	**11.9**

Moisture Content
8.02

D_{60}= 15.43	D_{30}= 1.37	D_{10}= #N/A

Cu = D60/D10 =	**#N/A**	#N/A
Cc = D30^2/(D10*D60) =	**#N/A**	#N/A

DESCRIPTION: sandy GRAVEL
some silt

USCS: GP

TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	

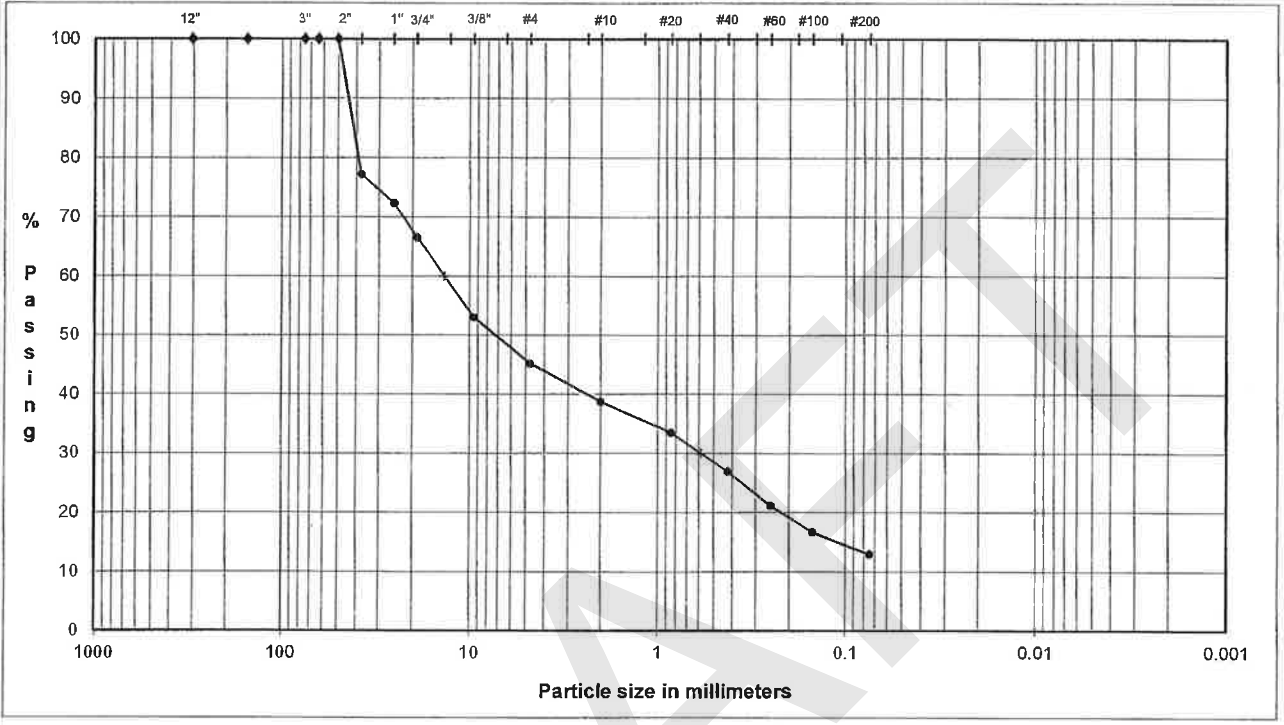
DRAFT

12/4/13 123-99755-01.001

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: **G&O / Olympia Meridian Geotech / WA**
SAMPLE ID: **TP-04** **S-2** Depth: **5ft**
TYPE: **-**



	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay
COBBLES	GRAVEL		SAND			FINES

U.S. Standard Sieves Sizes and Numbers

Sieve	Particle Size (mm)	% Passing	Particle Size Classification	Percentage
12.0"	304.8	100.0	Cobbles	0.0
6.0"	154.2	100.0		
3.0"	75	100.0		
2.5"	63.5	100.0	Coarse Gravel	33.4
2.0"	50	100.0		
1.5"	37.5	77.2		
1.0"	25	72.4		
0.75"	19	66.6		
0.375"	9.5	53.1	Fine Gravel	21.4
#4	4.75	45.2		
#10	2.00	38.7	Coarse Sand	6.5
#20	0.85	33.5	Medium Sand	11.7
#40	0.43	27.0		
#60	0.25	21.2	Fine Sand	14.0
#100	0.15	16.7		
#200	0.075	13.0		
			Fines	13.0

Moisture Content: 8.39

D_{60}= 13.57	D_{30}= 0.59	D_{10}= #N/A
Cu = D60/D10 =	#N/A	#N/A
Cc = D30^2/(D10*D60) =	#N/A	#N/A

DESCRIPTION: sandy GRAVEL
some silt

USCS: GP

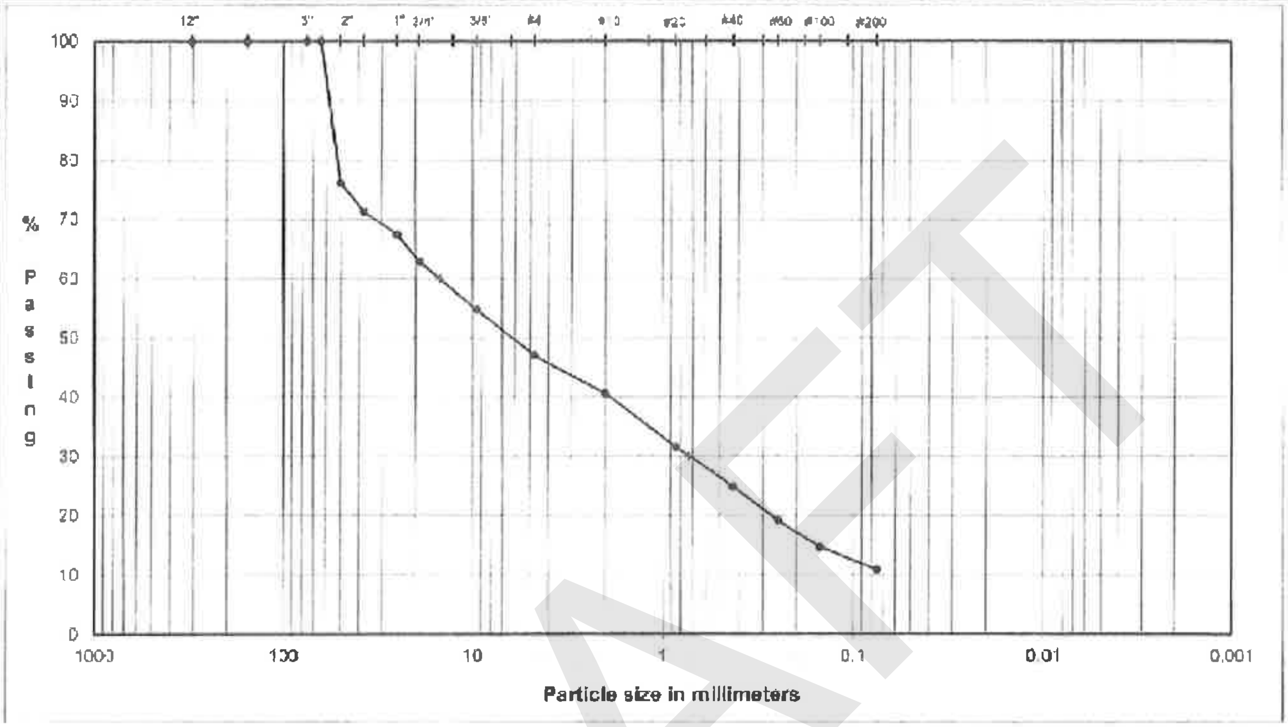
TECH	TM
DATE	12/4/13
CHECK	TCM
REVIEW	

DRAFT

PARTICLE SIZE DISTRIBUTION

ASTM D421, D422, D4318

PROJECT NAME: G&O / Olympia Meridian Geotech / WA
SAMPLE ID: TP-04 S-3 Depth: 7ft
TYPE: -



	Coarse	Fine	Coarse	Medium	Fine	Silt or Clay
COBBLES	GRAVEL		SAND			FINES

U.S. Standard Sieves Sizes and Numbers

	Particle Size (mm)	% Passing	Particle Size Classification	Percentage
12.0"	304.8	100.0	Cobbles	0.0
6.0"	154.2	100.0		
3.0"	75	100.0		
2.5"	63.5	100.0	Course Gravel	37.1
2.0"	50	76.2		
1.5"	37.5	71.3		
1.0"	25	67.5		
0.75"	19	62.9		
0.375"	9.5	54.8	Fine Gravel	15.9
#4	4.75	47.1		
#10	2.00	40.6	Course Sand	6.4
#20	0.85	31.6	Medium Sand	15.8
#40	0.43	24.8		
#60	0.25	19.2	Fine Sand	13.9
#100	0.15	14.8		
#200	0.075	10.9		
			Fines	10.9

Moisture Content
8.09

D_{60}= 14.82	D_{30}= 0.72	D_{10}= #N/A

Cu = D60/D10 =	#N/A	#N/A
Cc = D30^2/(D10*D60) =	#N/A	#N/A

DESCRIPTION: GRAVEL and SAND
some silt

USCS: GP

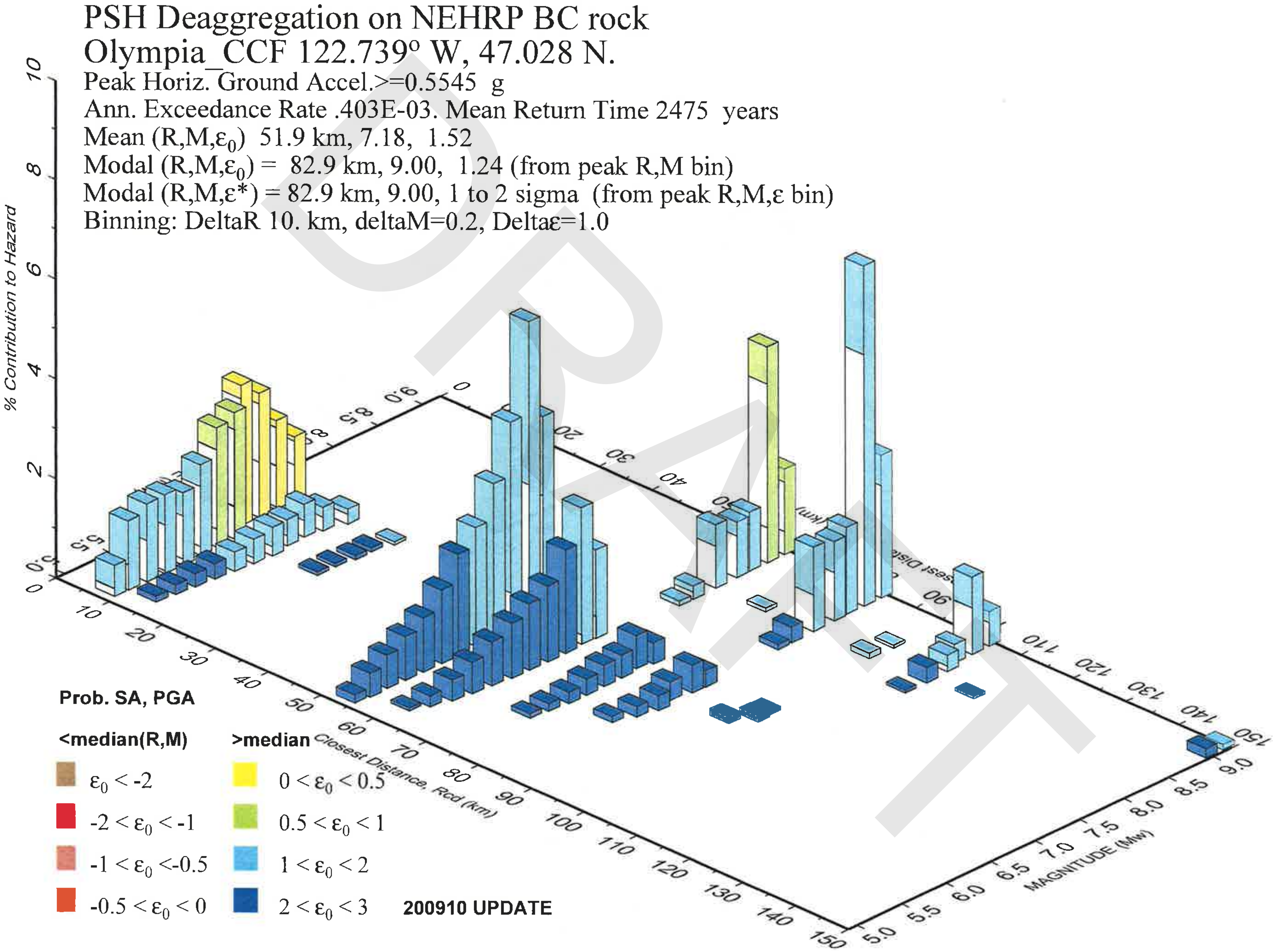
TECH	TM
DATE	12/4/13
CHECK	JCM
REVIEW	

DRAFT

Appendix C

SEISMIC DEAGGREGATION PLOTS

DRAFT



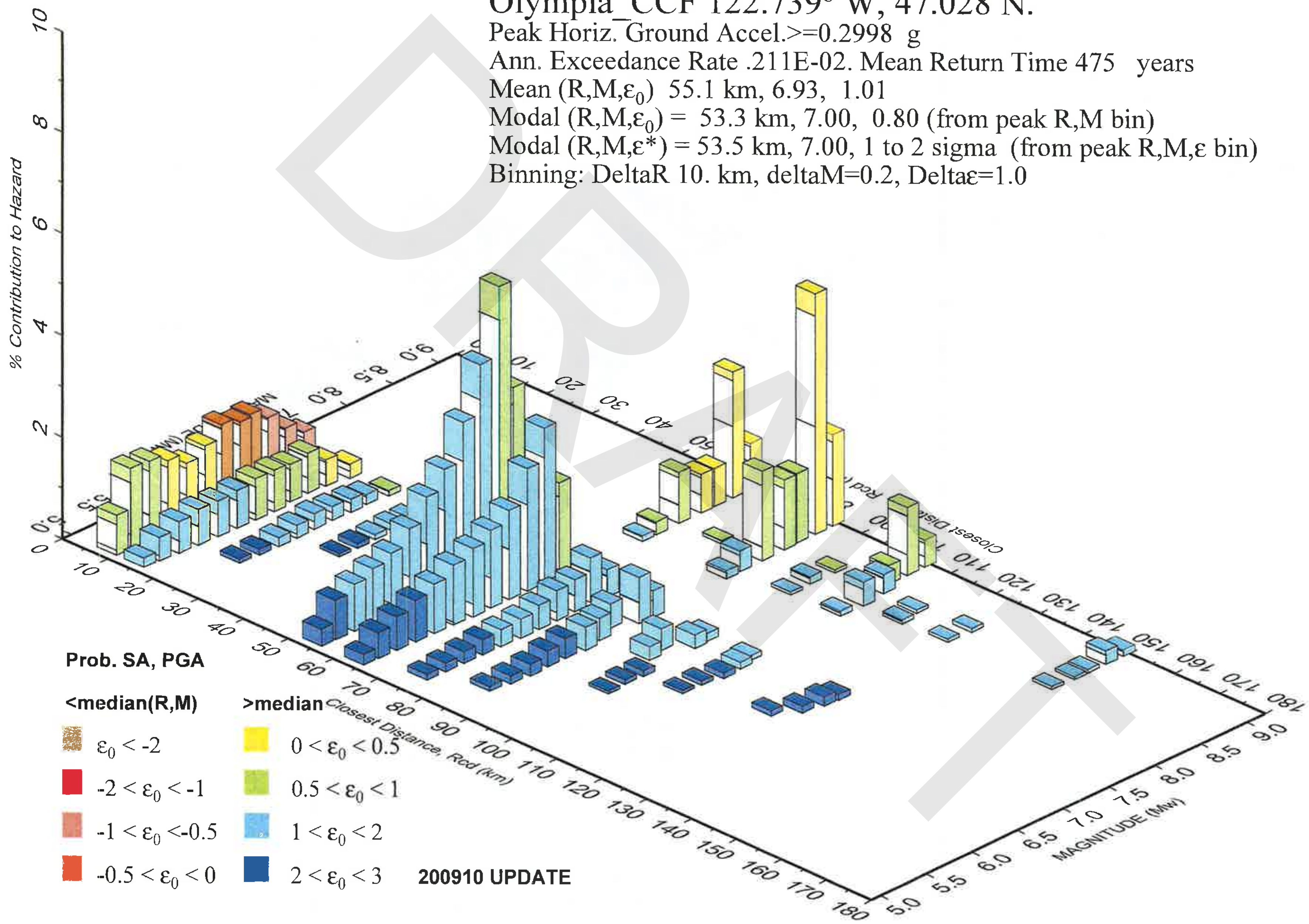
PSH Deaggregation on NEHRP BC rock
Olympia_CCF 122.739° W, 47.028 N.
Peak Horiz. Ground Accel.>=0.5545 g
Ann. Exceedance Rate .403E-03. Mean Return Time 2475 years
Mean (R,M,ε_0) 51.9 km, 7.18, 1.52
Modal (R,M,ε_0) = 82.9 km, 9.00, 1.24 (from peak R,M bin)
Modal (R,M,ε^*) = 82.9 km, 9.00, 1 to 2 sigma (from peak R,M,ε bin)
Binning: DeltaR 10. km, deltaM=0.2, Deltaε=1.0

DRAFT

GMT 2014 Jan 6 20:37:02 Distance (R), magnitude (M), epsilon (E0,E) deaggregation for a site on rock with average vs= 760. m/s top 30 m. USGS CGHT PSHA2008 UPDATE Bins with lt 0.05% contrib. omitted

PSH Deaggregation on NEHRP BC rock
Olympia_CCF 122.739° W, 47.028 N.

Peak Horiz. Ground Accel.>=0.2998 g
Ann. Exceedance Rate .211E-02. Mean Return Time 475 years
Mean (R,M,ε_0) 55.1 km, 6.93, 1.01
Modal (R,M,ε_0) = 53.3 km, 7.00, 0.80 (from peak R,M bin)
Modal (R,M,ε^*) = 53.5 km, 7.00, 1 to 2 sigma (from peak R,M,ε bin)
Binning: DeltaR 10. km, deltaM=0.2, Deltaε=1.0



DRAFT

GMT 2014 Jan 6 20:37:12 Distance (R), magnitude (M), epsilon (E0,E) deaggregation for a site on rock with average vs= 760. m/s top 30 m. USGS CGHT PSHA2008 UPDATE Bins with lt 0.05% contrib. omitted

Database Search

Complete Report for Southern Whidbey Island fault zone (Class A) No. 572

Brief Report ||Partial Report

citation for this record: Johnson, S.Y., Blakely, R.J., Brocher, T.M., Sherrod, B.L., Kelsey, H.M., and Lidke, D.J., compilers, 2004, Fault number 572, Southern Whidbey Island fault zone, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, http://earthquakes.usgs.gov/hazards/qfaults, accessed 04/23/2013 03:16 PM.

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Synopsis This northwest-trending fault zone extends more than 65 km across Possession Sound, southern Whidbey Island, Admiralty Inlet into the eastern Strait of Juan de Fuca. The fault zone is as wide as 5-7 km, correlates with gravity and magnetic anomalies (Finn and others, 1991 #4753; Blakely and others, 1999 #4747), and has been interpreted as a complex zone of transpressional deformation (Johnson and others, 1996 #4751).

Name comments Gower (1980 #6229) showed and named the "southern Whidbey Island fault," and Gower and others (1985 #4725) showed this fault on their seismotectonic map of the Puget Sound region and briefly outlined its geologic relationships. Wagner and Wiley (1983 #6230) and Wagner and Tomson (1987 #6249) mapped and briefly discussed offshore parts of this fault zone and also used the name "southern Whidbey Island fault." Johnson and others (1996 #4751) described multiple sub-parallel strands and referred to the overall structure as the "southern Whidbey Island fault zone," and this name is also used herein for this zone of faults that crosses the southern part of Whidbey Island.

County(s) and State(s)
, WASHINGTON
ISLAND COUNTY, WASHINGTON
JEFFERSON COUNTY, WASHINGTON
SNOHOMISH COUNTY, WASHINGTON

Physiographic province(s) PACIFIC BORDER

Reliability of location Good
Compiled at 1:100,000 scale.

Comments: The offshore location of the southern Whidbey Island fault zone is relatively well constrained based on interpretation of a dense network of industry and high-resolution seismic-reflection profiles (Johnson and others, 1996 #4751; Dadisman and others, 2000 #4748; Johnson and others, 2000 #4750; 2000 #4755). Onshore, strands of the southern Whidbey Island fault zone are generally concealed beneath a cover of dense vegetation and thick Pleistocene glacial and interglacial deposits. Approximate locations of fault strands are by S.Y. Johnson and based on available geologic and geophysical data, mainly from Johnson and others(1996 #4751; 2000 #4750).

Geologic setting The northwest-trending southern Whidbey Island fault zone occurs along a significant terrane boundary between basement blocks underlain by Eocene marine basalts of the Coast Range province to the southwest and pre-Tertiary metamorphic rocks of the Cascades province to the northeast. However, seismic tomography studies (Brocher and others, 2001 #4718) reveal that only the northwestern end of the fault zone in the southeastern Strait of Juan de Fuca is associated with a strong velocity contrast. The southeastern and central parts of the southern Whidbey Island fault zone form the southwest margin of the Everett basin and northeast boundary of the Seattle basin. The northwestern part of the fault zone forms the northeastern limit of the Port Townsend basin (Brocher and others, 2001 #4718).

Length (km) 64 km.

Comments:

The map shows the minimum fault length (~65 km). At its northwest end, seismic-reflection data indicate the southern Whidbey Island fault zone does not continue west of 123?. The southern Whidbey Island fault zone could continue more than 20 km farther to the southeast along the flanks of a moderate amplitude aeromagnetic anomaly (Blakely and others, 1999 #4747).

Average strike N51°W

Sense of movement Thrust

USGS Design Maps Summary Report

User–Specified Input

Report Title	Olympia CCF Tue January 7, 2014 18:30:18 UTC
Building Code Reference Document	2012 International Building Code (which utilizes USGS hazard data available in 2008)
Site Coordinates	47.02822°N, 122.73904°W
Site Soil Classification	Site Class D – "Stiff Soil"
Risk Category	I/II/III

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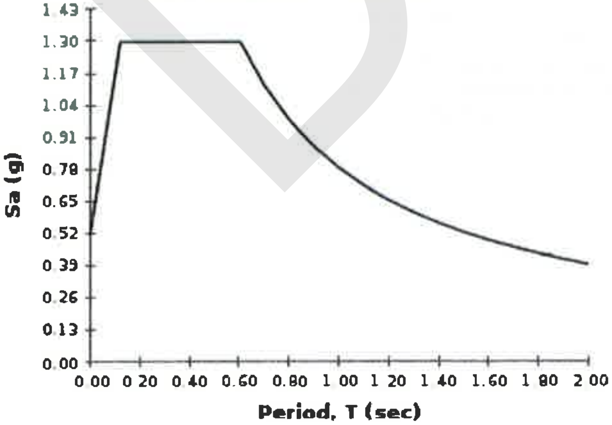
USGS–Provided Output

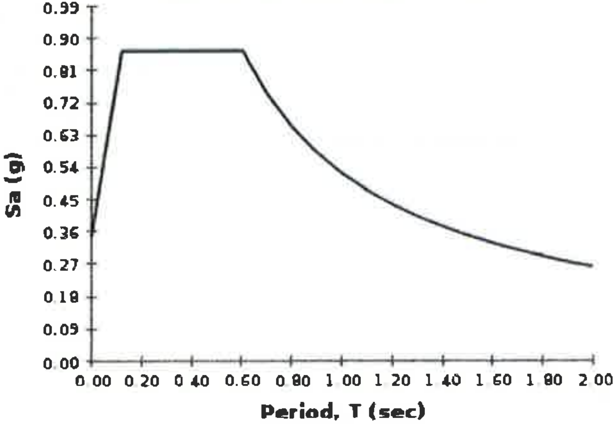
S_S = 1.297 g	S_{MS} = 1.297 g	S_{DS} = 0.864 g
S_1 = 0.523 g	S_{M1} = 0.785 g	S_{D1} = 0.523 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.

MCE_R Response Spectrum



Design Response Spectrum



Although this information is a product of the U.S. Geological Survey, we provide no warranty, expressed or implied, as to the accuracy of the data contained therein. This tool is not a substitute for technical subject-matter knowledge.

USGS Design Maps Detailed Report

2012 International Building Code (47.02822°N, 122.73904°W)

Site Class D – "Stiff Soil", Risk Category I/II/III

Section 1613.3.1 — Mapped acceleration parameters

Note: Ground motion values provided below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_S) and 1.3 (to obtain S_1). Maps in the 2012 International Building Code are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 1613.3.3.

From Figure 1613.3.1(1) [1] $S_S = 1.297$ g

From Figure 1613.3.1(2) [2] $S_1 = 0.523$ g

Section 1613.3.2 — Site class definitions

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class D, based on the site soil properties in accordance with Section 1613.

2010 ASCE-7 Standard – Table 20.3-1
SITE CLASS DEFINITIONS

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index *PI* > 20, • Moisture content *w* ≥ 40%, and • Undrained shear strength $\bar{s}_u$ < 500 psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

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Section 1613.3.3 — Site coefficients and adjusted maximum considered earthquake spectral response acceleration parameters

TABLE 1613.3.3(1)
VALUES OF SITE COEFFICIENT F_a

Site Class	Mapped Spectral Response Acceleration at Short Period				
	$S_S \leq 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_S

For Site Class = D and S_s = 1.297 g, F_a = 1.000

TABLE 1613.3.3(2)
VALUES OF SITE COEFFICIENT F_v

Site Class	Mapped Spectral Response Acceleration at 1-s Period				
	$S_1 \leq 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \geq 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7 of ASCE 7				

Note: Use straight-line interpolation for intermediate values of S_1

For Site Class = D and S_1 = 0.523 g, F_v = 1.500

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Equation (16-37): $S_{MS} = F_aS_S = 1.000 \times 1.297 = 1.297$ g

Equation (16-38): $S_{M1} = F_vS_1 = 1.500 \times 0.523 = 0.785$ g

Section 1613.3.4 — Design spectral response acceleration parameters

Equation (16-39): $S_{DS} = ⅔\, S_{MS} = ⅔ \times 1.297 = 0.864$ g

Equation (16-40): $S_{D1} = ⅔\, S_{M1} = ⅔ \times 0.785 = 0.523$ g

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Section 1613.3.5 — Determination of seismic design category

TABLE 1613.3.5(1)
SEISMIC DESIGN CATEGORY BASED ON SHORT-PERIOD (0.2 second) RESPONSE ACCELERATION

VALUE OF S_{DS}	**RISK CATEGORY**		
	I or II	**III**	**IV**
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D	D	D

For Risk Category = I and S_{DS} = 0.864 g, Seismic Design Category = D

TABLE 1613.3.5(2)
SEISMIC DESIGN CATEGORY BASED ON 1-SECOND PERIOD RESPONSE ACCELERATION

VALUE OF S_{D1}	**RISK CATEGORY**		
	I or II	**III**	**IV**
$S_{D1} < 0.067g$	A	A	A
$0.067g \leq S_{D1} < 0.133g$	B	B	C
$0.133g \leq S_{D1} < 0.20g$	C	C	D
$0.20g \leq S_{D1}$	D	D	D

For Risk Category = I and S_{D1} = 0.523 g, Seismic Design Category = D

Note: When S_1 is greater than or equal to 0.75g, the Seismic Design Category is **E** for buildings in Risk Categories I, II, and III, and **F** for those in Risk Category IV, irrespective of the above.

Seismic Design Category ≡ "the more severe design category in accordance with Table 1613.3.5(1) or 1613.3.5(2)" = D

Note: See Section 1613.3.5.1 for alternative approaches to calculating Seismic Design Category.

References

1. *Figure 1613.3.1(1)*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/IBC-2012-Fig1613p3p1(1).pdf
2. *Figure 1613.3.1(2)*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/IBC-2012-Fig1613p3p1(2).pdf

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ATTACHMENT B

VICINITY MAP

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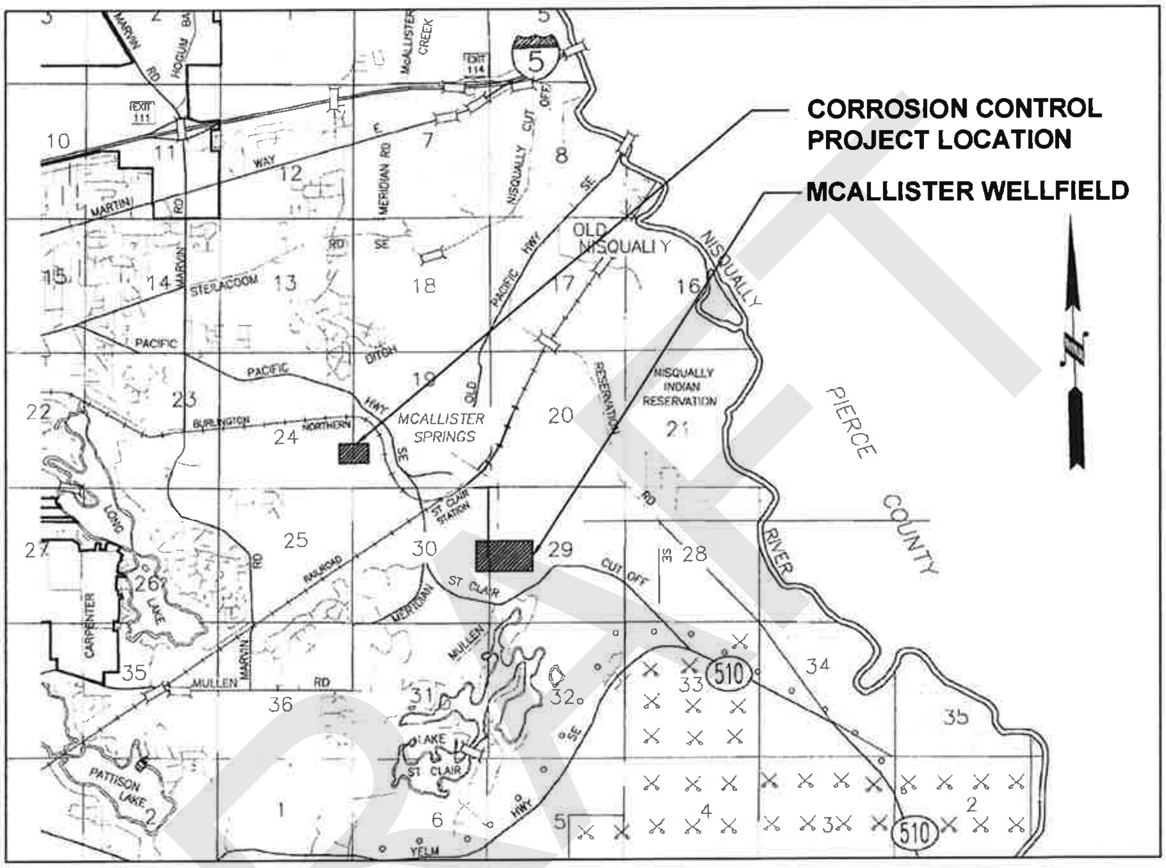

VICINITY MAP
NOT TO SCALE

CITY OF OLYMPIA

CORROSION CONTROL FACILITY
VICINITY MAP

Gray & Osborne, Inc.
CONSULTING ENGINEERS

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ATTACHMENT C

SITE PLAN MAP

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OVERALL SITE PLAN

SCALE: 1=80'-0"

PROPERTY LINE SETBACK DISTANCES:

	EXISTING VALVE HOUSE	PROPOSED BLOWER BUILDING	PROPOSED AERATION TOWERS	EXISTING MERIDIAN RESERVOIR NO. 1	EXISTING MERIDIAN RESERVOIR NO. 2
NEAREST DSITANCE TO NORTHERN PROPERTY LINE (FEET)	192	173	206	259	529
NEAREST DISTANCE TO SOUTHERN PROPERTY LINE (FEET)	513	524	435	279	445
NEAREST DISTANCE TO WESTERN PROPERTY LINE (FEET)	497	626	610	391	172
NEAREST DISTANCE TO EASTERN PROPERTY LINE (FEET)	337	236	237	301	522

PROPOSED STRUCTURES	SQUARE FOOTAGE	HEIGHT
CORROSION CONTROL FACILITY	2,700 SF	30 FT
MECHANICAL BUILDING	320 SF	12 SF
EXISTING STRUCTURES	**SQUARE FOOTAGE**	**HEIGHT**
RESERVOIR NO. 1	28,340 SF	VARIES 9-17 FT
RESERVOIR NO. 2	28,340 SF	VARIES 9-17 FT
EXISTING VALVE HOUSE	864 SF	12 FT
LACEY RESERVOIR	3,300 SF	100 FT
LACEY BOOSTER STATION BUILDING	400 SF	10 FT

—— APPROXIMATE BOUNDARY OF EXISTING VEGETATION. ALL EXISTING NATIVE VEGETATION TO REMAIN

MAP INFORMATION

HORIZONTAL DATUM: CITY OF OLYMPIA COORDINATE SYSTEM
VERTICAL DATUM: NGVD 1929
SITE ADDRESS: 9441 PIPERHILL DR SE
PARCEL NUMBER: 11824440200

DIRECTIONS:

1. TAKE EXIT 111 ON INTERSTATE 5 FOR MARVIN ROAD
2. TRAVEL SOUTH ALONG MARVIN ROAD FOR 1.5 MILES
3. AT THE TRAFFIC CIRCLE CONTINUE STRAIGHT ONTO MARVIN ROAD SE FOR 0.7 MILES
4. TURN LEFT ONTO 19TH AVENUE SE AND CONTINUE 0.9 MILES
5. TURN LEFT ONTO PIPERHILL DR SE AND CONTINUE 0.5 MILES
6. TURN RIGHT AND CONTINUE UP THE HILL TO THE SITE. SECURITY GATE AT SITE ENTRANCE.

CITY OF OLYMPIA
CORROSION CONTROL FACILITY
SITE PLAN MAP

Gray & Osborne, Inc.
CONSULTING ENGINEERS

APPENDIX B

McALLISTER WELLFIELD CORROSION CONTROL OPTIMIZATION AND TREATMENT ANALYSIS

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CITY OF OLYMPIA

THURSTON COUNTY WASHINGTON

MCALLISTER WELLFIELD CORROSION CONTROL OPTIMIZATION AND ALTERNATIVES ANALYSIS

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G&O #12225.04
APRIL 2013

Gray & Osborne, Inc.
CONSULTING ENGINEERS

CITY OF OLYMPIA

THURSTON COUNTY WASHINGTON

MCALLISTER WELLFIELD CORROSION CONTROL OPTIMIZATION AND ALTERNATIVES ANALYSIS

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4/26/13

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4/24/13

G&O #12225.04
APRIL 2013

Gray & Osborne, Inc.
CONSULTING ENGINEERS

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EXECUTIVE SUMMARY

This report provides a corrosion control analysis for the new McAllister Wellfield. The report includes a review of background information, an assessment of existing distribution system water quality, assessment of blending impacts on water quality, identification of target distribution system pH, and a discussion of corrosion control alternatives for the new McAllister Wellfield. The report also makes recommendations for corrosion control alternatives for the Kaiser and Indian Summer wells, which are other City sources that are not currently treated for corrosion control.

BACKGROUND INFORMATION

The report provides background information pertinent to the understanding of corrosion control optimization including a review of previous studies, source water quality, Lead and Copper Rule considerations, corrosion control theory, water chemistry, and scale stability.

Source Water Quality

The report compares the water quality results from McAllister Wells taken during test pumping in 2012 and 2013 with historical McAllister Spring water quality and the water quality of the City's other groundwater sources.

The comparison shows that McAllister Wellfield has very similar water quality characteristics to McAllister Springs, with the primary difference being that the McAllister Wellfield pH and alkalinity are slightly lower than McAllister Springs.

Additionally, the McAllister Wellfield has similar inorganic water quality to most of the City's other groundwater sources. The Indian Summer Well has inorganic water quality characteristics that are different from the other sources including lower hardness, higher sodium, and generally lower total dissolved solids. This difference likely accounts for the increase in customer complaints that the City receives when the Indian Summer Well is operated. The pH of the McAllister Wellfield water is lower than most of the other City water sources following treatment except the Kaiser Well. However, if corrosion control treatment is installed at the McAllister Wellfield, the pH would be elevated similar to the other City sources.

Lead and Copper Rule

The City is required under the Lead and Copper Rule (LCR) to sample for lead and copper at selected tap sites throughout the distribution system. Since the City installed corrosion control at the Allison and Shana Park Wells, the City has been in complete compliance with the LCR. During the 2006, 2009, and 2012 sampling periods, none of the lead and copper samples were above the federally mandated Action Level.

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Because the City provides water to over 50,000 customers, it is classified as a large system. Large systems must demonstrate optimal corrosion control treatment. Washington Department of Health will establish operational conditions and targets based upon their review of this report.

Corrosion Control Theory and Water Chemistry

The report summarizes corrosion literature including EPA Guidance Manuals. From these documents, pH adjustment is the recommended approach for corrosion control water sources with the pH and alkalinity characteristics of the McAllister Wellfield. The City's Water System Plan identified an ideal pH range of 7.5 to 8.0 based upon a previous technical memorandum by HDR.

Scale Stability

Changes in source water quality can affect water quality in the distribution system. One potential concern is scale stability. Plumbing systems accumulate a layer on their interior surfaces, called scale, that results from the chemical interaction of the plumbing material and the water. Most scales actually protect plumbing surfaces by inhibiting corrosion through a process called passivation. If there are significant water quality changes, it is possible that scale chemistry can change. In some cases, the existing scale can dissolve, releasing accumulated scale products into the water and possibly accelerating corrosion.

The report provides a chemical analysis of potential scale effects anticipated with using McAllister Wellfield water. The analysis is based upon equilibrium chemistry for solids dissolution and soluble metal complexes for copper and lead. Assuming that the pH of the McAllister Wellfield water is adjusted to approximately 7.5, no adverse scale stability impacts are anticipated from bringing the McAllister Wellfield source on line.

DISTRIBUTION SYSTEM WATER QUALITY ANALYSIS

The report contains an analysis of the distribution system water quality and potential impacts due to changing from the McAllister Springs to the McAllister Wellfield.

Copper/pH Relationship

Copper sampling data for 2009 and 2012 and the corresponding average pH data within each pressure zone were reviewed. The correlation between the average zonal pH and copper data indicate a decrease in copper concentration as pH is increased. The average copper level for pH 6.8-6.9 was approximately twice the level seen at pH 7.1-7.2.

Assessment of Potential Water Quality Changes

An assessment of potential water quality changes in the distribution system was completed. The assessment used the combination of the City's existing hydraulic model

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and a water quality blending model to predict the impact of using McAllister Wellfield water. Based on the background corrosion data, the City's copper and pH data, and the results of the assessment of potential water quality changes, the report recommends a target pH of 7.5 in the distribution system for corrosion control optimization.

MCALLISTER WELLFIELD TREATMENT ANALYSIS

The report evaluates the potential treatment alternatives to produce McAllister Wellfield water at pH 7.5 or higher. Alternatives evaluated include spray nozzles, diffused bubble aeration, packed tower aeration, and caustic soda addition. Spray nozzles are eliminated in a cursory analysis because they are not able to remove carbon dioxide sufficiently to raise the pH to 7.5. Diffused bubble aeration and packed tower aeration both increase pH through removal of carbon dioxide. Caustic soda addition increases pH and alkalinity through addition of sodium hydroxide, which reacts with the dissolved carbon dioxide to form carbonate species.

The analysis uses design parameters from other installations, past studies, and Gray & Osborne experience to develop capital and operations and maintenance costs. The costs are used to develop a life-cycle cost analysis, the results of which are presented in Table E-1.

TABLE E-1

Life-Cycle Cost Analysis Summary

	Packed Towers	Diffused Bubble	Caustic Soda Addition
Capital Cost	$3,305,000	$2,650,000	$973,000
Annual O&M Costs	$100,000	$720,000	$747,000
20-Year Life-Cycle Cost	**$5,335,000**	**$17,883,000**	**$14,850,000**

The data in Table E-1 indicate that the most cost effective option in terms of life-cycle cost is packed tower aeration. The other two options are less expensive to construct but have significantly higher operations and maintenance costs. Diffused bubble aeration has high power costs for its blowers and caustic soda addition has higher costs due to the purchase and delivery of caustic soda solution.

In addition to the life cycle cost, the analysis considers other factors such as safety, ease of maintenance, operational flexibility, and environmental impacts. Packed tower aeration was rated the best alternative among the three treatment options with regard to these items as well.

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CORROSION OPTIMIZATION AT INDIAN SUMMER WELL

Because the Indian Summer Well has a relatively high pH of approximately 7.6, it is already above the 7.5 pH target of the distribution system. Consequently, it should be considered optimized for corrosion control.

CORROSION OPTIMIZATION AT KAISER WELL

The Kaiser Well produces water with a low pH at 6.4-6.6, thus it must be treated to optimize corrosion control. Since the Kaiser Well pumps directly to the distribution system, only packed tower aeration and caustic soda addition are the only suitable alternatives. A similar analysis to that performed for the McAllister Wellfield was performed for the Kaiser Well source. The results of the 20 year life-cycle cost analysis are shown in Table E-2.

TABLE E-2

Life-Cycle Cost Analysis Summary

	Packed Towers	**Caustic Soda Addition**
Capital Cost	$605,000	$343,000
O&M Costs	$12,000	$30,000
20-Year Life-Cycle Cost	**$836,000**	**$907,000**

Based on this evaluation, the recommended treatment alternative for the Kaiser Well is a packed tower. Since the Kaiser Well only produces 360 gpm, and has limited water rights, another alternative would be for the City to declare the Kaiser Well an emergency source and leave it untreated.

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INTRODUCTION

The City of Olympia (City) has contracted with Gray & Osborne, Inc. to complete a corrosion control analysis for the McAllister Wellfield project. As part of this analysis, the optimum distribution system pH for corrosion control will be assessed. This analysis includes a review of background information, an assessment of existing distribution system water quality, scale chemistry, identification of a target distribution system pH, analysis of water quality blending issues, and development of corrosion control alternatives for the new McAllister Wellfield. The City has also requested that corrosion control alternatives be evaluated for the Kaiser and Indian Summer wells.

A significant portion of the report is a blending analysis to assess the effect of using McAllister Wellfield water in place of McAllister Springs. The analysis uses the City's hydraulic model and a water quality blending model to investigate the expected water quality at various places throughout the distribution system. The analysis is designed to investigate the expected water quality, both for corrosion control and for general water quality issues such as scale stability and possible aesthetic concerns.

The City is in the process of developing the McAllister Wellfield to replace the McAllister Springs source. The wellfield will draw from the same aquifer as the springs, but will be withdrawn hydraulically upgradient prior to any surface water influence. As part of the wellfield project, corrosion control facilities will be installed. This corrosion control analysis is required by the Washington State Department of Health (DOH) to maintain compliance with the Lead and Copper Rule.

BACKGROUND INFORMATION

To provide context for the corrosion control analysis, a summary of background information is presented. This information includes previous City studies, a summary of source water quality, a brief overview of City compliance with lead and copper regulations, general corrosion control information, and a discussion of scale stability.

PREVIOUS STUDIES

The City has performed previous work regarding corrosion control and the potential impact of switching the McAllister source from the springs to the wellfield. Two of these reports are summarized below.

Economic and Engineering Services, McAllister Springs/Meridian Reservoir Corrosion Control Facility Pre-Design Report, 1996

Following the State's adoption of the U.S. Environmental Protection Agency's (EPA's) Lead and Copper Rule in 1995, the City examined corrosion control options for McAllister Springs as a way of reducing copper concentrations within the distribution system.

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This report examined four options for increasing spring water pH by removing carbon dioxide including packed tower aeration, multiple tray aeration, spray nozzle aeration, and diffused air aeration at the Meridian Reservoirs. In addition to considering cost and operational issues, pilot studies were conducted to determine the ability of diffused air and packed tower aeration to elevate the spring water pH. The studies varied water flow rate, airflow rate, air-to-water ratios, water depth, and liquid loading rate.

The packed tower pilot study showed fairly similar final pH levels (7.7 to 7.9) for a variety of air-to-water ratios. Since air-to-water ratios greater than five were thought by the study's authors to have no added effect on CO_2 removal, the liquid loading rate was the primary factor for determining final pH in the study. Due to the consistent results of the pilot study, the report does not determine a specific pH operating point, stating that other conditions such as power requirements and costs must also be considered.

The diffused air pilot study results were less clear than that for the packed towers, yet still indicated a final pH of over 7.5 would be achieved. For diffused aeration, the air-to-water ratio, liquid detention time, and diffuser depth all contribute significantly to results. The pilot study accounts for these factors; however, its ability to accurately predict pH increase in actual implementation can only be inferred based on the relative accuracy of the pilot study.

Based on pilot studies and data available from other systems, the only methods considered capable of reliably elevating the pH from McAllister Springs were packed towers and diffused air. The predesign report recommended diffused air over packed towers due to cost and potential challenges maintaining CT since chlorine is more effective at lower pH values. Treatment was never installed at the springs, primarily because lead and copper levels were reduced after installing treatment at other sources, and because the City had already initiated wellfield project planning.

HDR, Technical Memorandum/Wellfield Transition Water Quality Assessment, March 2008

As part of the City's 2009 Water System Plan, the City assessed the potential impact of changing from McAllister Springs to the McAllister Wellfield in a technical memorandum. The memorandum provided a system overview, comparison of water quality between the McAllister Wellfield and McAllister Springs and the other City sources, and a discussion of water quality. The report recommended that the wellfield water pH be raised above 7.5 to provide corrosion control and minimize scale dissolution.

SOURCE WATER QUALITY

There are two major considerations for source water quality. The first is a comparison of McAllister Springs and the McAllister Wellfield water quality, while the second is a comparison of the McAllister Wellfield water quality with the other City sources. This

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section presents those two comparisons. Table 1 contains water quality data for all active sources and the McAllister Wellfield.

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TABLE 1

Comparison of Inorganic Analytes, pH, Alkalinity for McAllister Springs, Wellfield and Other City Sources

Analyte	McAllister Well TW-22	McAllister Well PW-24	McAllister Well PW-25	McAllister Springs		Kaiser Well 1	Shana Park Well 11	Allison Well 13	Allison Well 19	Indian Summer Well 20
	Sep. '12	**Jan. '13**	**Feb. '13**	**Apr. '11**	**Aug. '12**	**Sep. '04**	**Avg.(1)**	**Aug. '04**	**Aug. '04**	**Sep. '09**
Sodium, mg/L	6.6	7.7	5.8	6.88	7.1	<5	7.6	<5	5	20
Calcium Hardness, mg/L as $CaCO_3$	56	57.4	48.2	58	60.6	54	58.3	56	54	11.3
Conductivity, µmhos/cm	141	139	136	142	151	160	164	144	135	111
Turbidity, NTU	ND	0.75	0.21	0.14	0.44	1.68	0.33	0.1		0.1
Nitrate-N, mg/L	0.37	0.33	0.43	1.36	1.2	0.66	3.04	1.09	0.96	<0.5
Chloride, mg/L	4.4	4.5	4.3	4	4	<20	<20	<20	<20	2.1
Sulfate, mg/L	3.3	3.1	3.4	5.2	4.7	<10	<10	<10	<6	0.2
Iron, mg/L	ND	ND	ND	0.1	0.1	0.339	<0.1	<0.1	<0.1	0.092
Manganese, mg/L	ND	0.002	ND	0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.016
Fluoride, mg/L	ND	0.1	ND	0.5	0.5	0.2	0.2	0.2	0.23	0.25
Copper, mg/L	ND	ND	ND	0.02	0.02	0.2	0.2	0.2	0.02	0.02
TDS, mg/L	110	97	107	125	117 (2)	124 (2)	127 (2)	112 (2)	100	86 (2)
Date Range for pH and Alkalinity	**Sep. '12**	**Jan. '13**	**Feb. '13**	**Jan. '10 - Oct. '12**		**May - Aug. '12**	**May '10 - Nov. '11**	**May - Nov. '11**		**July - Sep. '11**
Total Alkalinity, mg/L as $CaCO_3$	54.6	55	54	60.5		58	49	48		53
pH	6.6	6.6	6.5	6.68		6.38	7.48 (2)	7.72 (2)		7.58
Aggressive Index	9.69	9.70	9.52	9.83	9.84	9.48	10.54	10.75	10.73	9.96
	Very	Very	Very	Very	Very	Very	Moderately	Moderately		Very
Langelier Index	-2.10	-2.08	-2.27	-1.97	-1.95	-2.32	-1.26	-1.04	-1.05	-1.82
	Not Scale Forming (aggressive)									

(1) Average of data from August 2004 and July 2005.

(2) TDS data not available so estimated using average ratio of Conductivity to TDS from other sources.

(3) Both Allison Springs Wells and Shana Park Wells are currently treated with packed tower aeration to remove dissolved CO_2 and increase pH. Values listed are after packed tower aeration treatment. Gray & Osborne pH measurements at Shana Park and Allison in February 2013 were 7.9 and 7.7, respectively.

McAllister Springs versus McAllister Wellfield

The City is required to sample McAllister Springs for various water quality parameters. Consequently, there is a good historical record for the springs. Sampling has been completed recently for TW-22, PW-24, and PW-25 in 2012 and 2013 as part of the wellfield development project.

The data in Table 1 indicate that the inorganic water quality of McAllister Springs and the wellfield is similar. The hardness and nitrate concentrations measured in all three wells are slightly lower than McAllister Springs but the difference is negligible. The conductivity and TDS values are similar indicating a similar level of overall dissolved solids. TW-22, PW-24, and PW-25 appear to have similar levels of chloride and sulfate compared to McAllister Springs.

Table 1 also shows a comparison of pH and alkalinity data for the springs and wellfield. The data show that the pH and alkalinity of both sources is comparable.

In conclusion, the comparison of McAllister Springs and Wellfield indicates that the water quality is similar with comparable levels of various anions, cations, and alkalinity. The pH of the McAllister Wellfield is either slightly lower than or the same as McAllister Springs.

McAllister Wellfield versus Other City of Olympia Sources

In order to understand the interaction of the McAllister Wellfield with the other City sources, a comparison of water quality must be made. Table 1 presents a comparison of inorganic water quality for the various City sources.

The data in Table 1 indicate that for most analytes, the McAllister Wellfield is similar to Kaiser, Shana Park, and Allison Wells 13 and 19. The Kaiser Well had iron at 0.339 mg/L, a level above the 0.3 mg/L maximum contaminant level (MCL).

The Indian Summer Well appears to have significant differences relative to the McAllister Wellfield. It has higher levels of sodium, lower hardness, and lower conductivity suggesting a lower level of dissolved solids.

The City's SCADA system records pH levels at many of the sources on a daily basis. Daily pH levels fluctuate at each source, typically by ±0.5 pH. Table 1 compares average pH levels and alkalinity per source compared to the 2012 and 2013 data for TW-22, PW-24, and PW-25.

The pH levels of Allison Springs Wells, Indian Summer Well, and Shana Park Wells are all significantly higher than the expected untreated pH of the McAllister Wellfield. The alkalinities of these sources are similar to the McAllister source. The Kaiser Well has a lower pH than the McAllister Wellfield and is comparable in alkalinity.

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In short, the expected differences between the McAllister Wellfield can be inferred from a comparison of the McAllister Springs and the other City sources. It is expected that most significant difference will be in terms of pH and alkalinity, if the McAllister Wellfield is untreated. In addition, the Indian Summer Well has significantly different water quality; namely lower hardness and dissolved minerals, but higher levels of iron and manganese.

Oxidation Reduction Potential (ORP)

Oxidation Reduction Potential (ORP) is a measure of the ability of the constituents of a chemical solution to acquire electrons (reduce) and in the process oxidize the electron donor. For drinking water, it is a measure of the ability of the water to oxidize pathogens. The ORP is measured in millivolts (mV) with higher measurements indicating more oxidation ability. It is a function of the various water quality constituents in solution and is mainly influenced by pH and the presence of a strong oxidant like chlorine. Gray & Osborne measured the ORP of the McAllister PW-24 water following pH adjustment and chlorine addition for comparison to the other City groundwater sources. The ORP data is included in Table 2.

TABLE 2

ORP Measurements for City Sources

Source	Raw Water ORP, mV	pH(1)	Free Chlorine, mg/L(2)	Final ORP, mV
McAllister PW-24 #1	122	7.9	1.05	612
McAllister PW-24 #2	113	7.3	1.06	675
McAllister PW-24 #3	110	6.6	0.97	697
Indian Summer	483	7.6	1.23	680
Shana Park	NA	7.9	1.38	668
Kaiser	NA	6.6	0.79	737
Allison	NA	7.7	1.13	693

(1) pH for McAllister PW-24 measured after bench-scale pH adjustment and chlorine addition. pH for Indian Summer, Shana Park, Kaiser, and Allison measured at wellhead or at wellhead after aeration treatment.

(2) Free chlorine was measured after sodium hypochlorite addition for PW-24 and Indian Summer during bench-top testing while Shana Park, Kaiser, and Allison chlorine measurements per chlorine analyzer at wellhead during sampling.

The data in Table 2 show the influence of pH and free chlorine on ORP measurements. Higher pH values correspond to lower ORP measurements for similar chlorine levels. In short, the chlorinated ORP values for the City's source and PW-24 are similar.

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Other Water Chemistry Considerations

Another aspect of water chemistry that should be considered is the effect of calcium compounds. In some systems, high levels of calcium can result in precipitation of calcium salts that can cause water spots and white deposits on fixtures, and affect water heater life and performance. Calcium salt precipitation can also provide passivation on corroding metal surfaces. In addition, calcium chemistry has an affect on cementitious materials like concrete reservoirs and asbestos concrete (AC) piping.

The Langlier Index is a method of indicating calcium salt solubility. As shown in Table 1, the Langlier Indices for the City's sources, including the McAllister Wells, are negative indicating that calcium salts are soluble in those waters and that no calcium precipitate is expected. The solubility of calcium salts is pH dependant and decreases as pH is increased. Consequently, calcium salts would be less soluble if the pH is adjusted upward. For example, for a source water with alkalinity of 60 mg/L as $CaCO_3$ and hardness equal to 55 mg/L as $CaCO_3$, the point at which calcite, the least soluble form of calcium carbonate, would reach saturation and begin to precipitate would be above pH 8.1. For aragonite, another crystalline form of calcium carbonate, the saturation point would be when the pH is increased above 8.2.

The Aggressiveness Index shown in Table 1 is measure of the aggressiveness of the water to cementitious material. In general, values below 10 indicate very aggressive water, values between 10 and 12 are moderately aggressive, and values above 12 are not aggressive. The data in the table indicate that some of the City's sources are very aggressive; mostly the sources with low pH and Indian Summer. The aerated sources at Allison and Shana Park are considered moderate. The Aggressiveness Index is the sum of the pH and two other terms; one each based on hardness and alkalinity. If the pH of McAllister well water is increased, the aggressiveness index would increase by the same amount. For example, if TW-22 water's pH was increased from 6.6 to 7.0, the Aggressiveness Index would increase to 10.09 and would be termed moderately aggressive. If the well water pH is increased to 7.8, the Aggressiveness Index of TW-22 would be 10.89, which is higher than any other source. In short, increasing the pH of the City's source waters will make them less aggressive toward cementitious materials like AC piping.

LEAD AND COPPER RULE

In 1991, the EPA promulgated the federal Lead and Copper Rule (LCR). The State of Washington adopted this rule in 1995, with minimal changes. In 2007, the EPA issued the Lead and Copper Rule Short Term Regulatory Revisions and Clarifications, which primarily clarified monitoring and notification requirements. Decreasing lead and copper concentrations is important because they have been linked to adverse health effects when consumed in drinking water.

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The LCR is intended to reduce the tap water concentrations of lead and copper that can occur when corrosive source water causes lead and copper to leach from water meters, brass fittings, soldered joints, piping, and other plumbing fixtures.

Ninety percent of the distribution system lead samples collected according to the procedures outlined in WAC 246-290 must have concentrations below the "Action Level" of 0.015 mg/L. Similarly, 90 percent of the copper samples must have concentrations less than 1.3 mg/L. Systems exceeding the action levels are required to provide public notification and implement a program for reducing lead and copper levels.

Initially, after the promulgation of the LCR, the City experienced copper levels above the Action Level and received complaints related to copper leaching. The City installed aeration for corrosion control at Shana Park Well and Allison Springs Wells, described in more detail later in this report. Following installation, lead and copper levels throughout the system declined. Sampling results for the City's entire distribution system for the years 2006, 2009, and 2012 are shown in Tables 3 and 4 for lead and copper, respectively.

TABLE 3

Lead Sampling for 2006, 2009, and 2012

Parameter	2006 Lead (mg/L)	2009 Lead (mg/L)	2012 Lead (mg/L)
Action Level, mg/L	0.015	0.015	0.015
State Reporting Limit, mg/L	0.002	0.002	0.002
Maximum Concentration Reported, mg/L	0.005	0.025	0.015
90th Percentile Concentration, mg/L	0.003	0.006	0.004
Samples Taken	35	36	37
Samples Exceeding Action Level	0	1	0
Minimum Concentration Reported, mg/L	<0.002	<0.001	<0.001

TABLE 4

Copper Sampling for 2006, 2009, and 2012

Parameter	2006 Copper (mg/L)	2009 Copper (mg/L)	2012 Copper (mg/L)
Action Level, mg/L	1.3	1.3	1.3
State Reporting Limit, mg/L	0.2	0.2	0.2
Maximum Concentration Reported, mg/L	1.100	1.005	1.260
90th Percentile Concentration, mg/L	0.962	0.927	0.890
Samples Taken	35	36	37
Samples Exceeding Action Level	0	0	0
Minimum Concentration Reported, mg/L	0.059	0.027	0.036

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As seen in Tables 3 and 4, sampling since 2006 has reported 90th percentile lead and copper levels below the Action Level.

One of the basic elements of the LCR is for water systems to optimize corrosion control, meaning that source water be treated to be minimally corrosive to limit lead and copper leaching from plumbing materials within the system. The City was recently reclassified as a large system, with over 50,000 customers. Large systems must demonstrate optimal corrosion control treatment (CCT) regardless of sampled lead and copper levels. This optimization requirement now applies to the City even though lead and copper levels are in compliance. To demonstrate optimal CCT, large water systems must conduct initial monitoring of source water treated by corrosion control, which DOH will then review and establish operational conditions and targets to be met during all routine monitoring.

Since the City is changing from the McAllister Springs source to the McAllister Wellfield, the City must evaluate corrosion control for the new source. Sampling from test wells in Table 1 indicate a pH comparable to or slightly lower than the springs, thus any previous corrosion control evaluations completed for the springs would likely apply to the wellfield.

In 1996, an aeration tower was installed for corrosion control at the Shana Park Well, replacing a soda-ash injection system that had not adequately reduced copper levels. At the same time, an aeration tower was also installed at the Allison Springs Wells for the same purpose. The installation of corrosion control at these two sources brought the City's subsequent copper sampling within LCR compliance.

Prompted by the change in the category of the City as it pertains to the LCR, the DOH issued a letter to the City summarizing the new requirements and assigning optimal water quality parameters.

At the Shana Park and Allison Springs Wells, the DOH letter assigned a minimum pH of 7.0 for both sources at distribution system entry. The City must report minimum, maximum, and average daily pH values twice a year to DOH. With regard to McAllister Springs and the Wellfield, the letter directed that "all wells will go through corrosion control evaluation as part of their source approval process." Treatment must be completed by August 2014. The letter also states that corrosion control studies must be submitted for the Kaiser Well and Indian Summer Well.

CORROSION CONTROL AND WATER CHEMISTRY

Lead and copper corrosion and subsequent release into drinking water is dependent upon the individual chemistry of the water in question. The 2011 American Water Works Association publication *Internal Corrosion Control in Water Distribution Systems* lists a number of water quality parameters that can influence lead and copper corrosion

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including pH, alkalinity, total dissolved solids, hardness, oxidants, sulfide, chloride, and sulfate among others.

For most systems, the water quality parameters of primary importance are pH and alkalinity. These parameters are generally addressed first when systems attempt to reduce corrosion. Only after these parameters are within industry accepted standards are the other parameters considered, and even then only in systems with treatment or complex water qualities. Since the City is already in compliance with LCR and has used pH control successfully at the Shana Park and Allison Springs wells, this analysis will focus only on pH and alkalinity.

The EPA published the *Lead and Copper Rule Guidance Manual, Volume 2 Corrosion Control Treatment* in 1992. This document categorizes pH as low when it is below 7.5, moderate between 7.5 and 9.0, and high when above 9.0. For alkalinity, the ranges are categorized as low when below 50 mg/L as $CaCO_3$, moderate when between 50 mg/L as $CaCO_3$ and 150 mg/L as $CaCO_3$, and high when above 150 mg/L as $CaCO_3$. The pH values for the untreated sources in Table 1 can be classified as low, while the treated sources at Allison Springs, Shana Park, and Indian Summer are moderate. The alkalinity of the various sources is approximately on the boundary between low and moderate.

In 2003, the EPA published the *Revised Guidance Manual for Selecting Lead and Copper Control Strategies*. The document provides a road map for selecting corrosion control strategies based upon water quality indicators including pH and dissolved inorganic carbon (DIC), a function of pH and alkalinity. Even though the City is in compliance with the LCR, the document still provides a useful exercise for reviewing corrosion optimization for the untreated sources. The recommended approach for source waters with pH less than 7.2 and DIC above 15 mg/L is to raise the pH incrementally by either aeration or chemical addition and observe results. The DIC for the City's untreated sources is between 24 and 28 mg/L. In contrast, for source water with a pH above 7.8 and DIC above 5 mg/L, the preferred approach is to add a chemical corrosion inhibitor such as orthophosphate. Consequently, it can be inferred that the optimal range for copper corrosion control by pH adjustment alone is appropriate between 7.2 and 7.8.

In its 2009 Water System Plan, the City identified an ideal pH range of 7.5 to 8.0 for the system to reduce copper corrosion by reducing dissolved carbon dioxide based on the HDR Technical Memorandum. Additionally, DOH has assigned a minimum target pH of 7.0 for the Allison Springs and Shana Park Wells although the aeration systems at both routinely provide a much higher pH.

The reason aeration is used to elevate pH is that it removes dissolved carbon dioxide. The dissolved carbon dioxide combines with water to form carbonic acid. During aeration, the dissolved carbon dioxide, and consequently the carbonic acid, is removed and pH is elevated.

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SCALE STABILITY

Distribution system piping and plumbing systems accumulate a layer, called scale, on their interior surfaces. When source water is changed, an additional water quality consideration is the effect on existing scales in system piping and the formation of new scales. If the source water changes the conditions to favor the solubility of the scale constituents, the scale can dissolve and the levels of metals in the water can rise. This can be problematic from both a regulatory standpoint (since many metals have MCLs), and from an aesthetic standpoint with tastes and odors.

From the analysis shown above, it is expected that if McAllister Wellfield water is introduced into the system at a similar pH to what has been measured historically for McAllister Springs, then there would be no expected change in scale stability. This is because the inorganic water quality difference between the two sources at the same pH is negligible.

To understand the effect of McAllister Wellfield water on scale solubility if the pH is not the same as the historical springs pH, an understanding of scale chemistry is essential. In short, corrosion scales are the byproduct of chemical complexation between ionized metals that have been oxidized from pipe material and various chemical ions, called ligands, in the water. The metal-ligand complexes can form insoluble material that deposits on the pipe surface to impede further corrosion of the pipe in a process called passivation. As the passivating layer is deposited on the pipe surface, the rate of corrosion slows, as does the release of metal into the water. Conversely, if the passivating layer dissolves due to water quality changes, corrosion of the pipe material resumes.

There are many ligands that can form metal-ligand complexes. For the City's water, the two main ligands are hydroxides from reactions with water and carbonates from alkalinity. Other ligands such as chloride, sulfate, and phosphates occur in such small concentrations relative to hydroxides and carbonates that their effect can be neglected. Consequently, this analysis will focus on hydroxides and carbonates.

The equilibrium behavior of metal-ligand complexes is governed by equations with empirically derived constants published in scientific literature. One method of displaying the equilibrium behavior is a Pourbaix diagram, also called a pE-pH diagram or an E(v)-pH diagram. A Pourbaix diagram shows the predominant species at any given E(v)-pH point. It is important to note that a Pourbaix diagram reflects equilibrium conditions and distribution system piping may or may not reflect equilibrium conditions. What is useful about the Pourbaix diagram is that the equilibrium conditions indicate in what direction a system may change if chemical conditions change; i.e., will a solid tend to dissolve if conditions change.

The pE or E(v) is a measurement of the oxidation reduction potential (ORP) of the aqueous solution. In short, it is the propensity of the solution to absorb or release

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electrons when a chemical species is introduced. An example for drinking water is a chlorinated solution, which would tend to absorb electrons from something introduced in the water in a process of oxidation. Consequently, if unchlorinated and chlorinated solutions of the same source water are compared, the chlorinated solution would have a higher ORP because a higher ORP reflects oxidation and a lower ORP reflects reduction. ORP is generally reported in millivolts (mV) because the potential of a solution can be directly measured relative to a standard electrode. The pE representation is analogous to the pH scale for H^+ concentration. E(v) and pE are related by the Nernst equation. In short, ORP can be represented by either pE or E(V). ORP measurements for the McAllister Wellfield and the other sources are shown in Table 2.

Figure 1 shows a Pourbaix diagram for the copper hydroxide system. The ORP in E(v) of McAllister Springs water and the other sources was measured between 600 and 740 mV as shown in Table 2. If an E(v) of 650 mV, or 0.65 V on the graph, is assumed for the wellfield, the species of copper that will be prevalent in the drinking water pH range is CuO (tenorite). The vertical lines in the diagram between Cu^{+2} and the CuO regions are labeled with the equilibrium line for the copper concentration expressed logarithmically. For example, for a molar concentration of 10^{-4} molar, the equilibrium between Cu^{+2} and CuO is expected to fall at approximately pH 6 as shown by the vertical line marked with a -4. Similarly, for a molar concentration of 10^{-6} molar copper (0.064 mg/L), the equilibrium boundary between Cu^{+2} and CuO is pH 7. The solubility of copper in this system can be inferred from the vertical lines. For example, as the pH is increased from 4 to 7, the solubility drops by a factor of 10^6. Although not specifically shown, this effect continues until the minimum solubility occurs at approximately pH 10. As pH is further increased, the solubility increases as CuO_2^{-2} becomes dominant. One thing that should be noted is that all of the copper species in the pH and E(v) range for Olympia water are cupric (Cu(II)) species rather than cuprous (Cu(I)) species.

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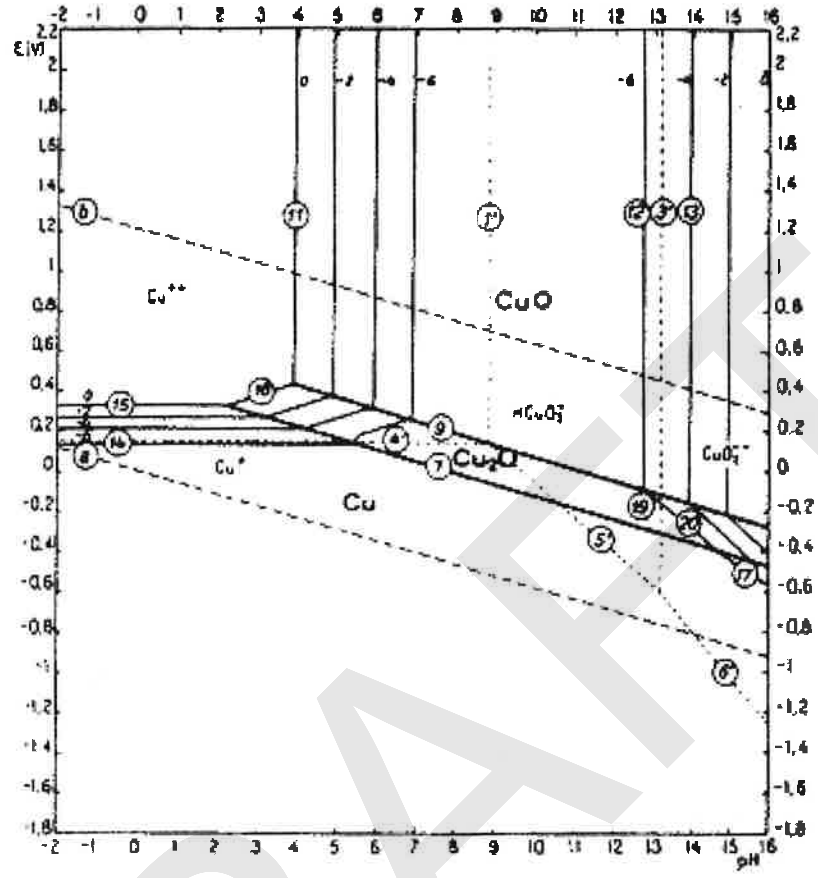

FIGURE 1

Pourbaix Diagram for Copper Hydroxide System (Reproduced from Pourbaix, 1966)

When carbonate is considered in conjunction with the hydroxide system, the picture becomes more complicated because carbonate species can act as ligands and form complexes. One way to analyze the potential effect of changing pH is to use chemical solubility equilibria to predict dissolution of copper complexes and display equilibria on plots of logarithmic concentration versus pH, called Log C-pH diagrams.

Figure 2 is a graph showing the modeling of chemical equilibria for copper species using equilibrium constant data from Benjamin (*Water Chemistry*, 2002). Solubility equilibrium equations can predict whether solids will dissolve and to what extent. For the City's water quality, the two copper solids that are of interest are tenorite (CuO) and malachite ($Cu_2(OH)_2CO_3$). $CuCO_3$ and $Cu(OH)_2$ were also included in the equilibria analysis, but are not shown on Figure 2 because they are much more soluble; i.e., they would likely dissolve only to precipitate as a less soluble species. Consequently, tenorite and malachite would be most likely to occur in aged pipe. Figure 2 shows the lines for tenorite and malachite in equilibrium with Cu^{+2} ions. Cu^{+2} ions will react with Cl^-, SO_4^{-2},

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OH^-, and CO_3^{-2} ions in the water to form various soluble complexes ($(Cu(Cl)_n^{2-n}$, $Cu(SO_4)_n^{1-2n}$, $Cu(OH)_n^{2-n}$ and $Cu(CO_3)_n^{1-2n}$). Equilibrium equations can be used to predict the concentrations of the various soluble species, the sum of which represents the total solubility line indicated on Figure 2. In short, Figure 2 shows the anticipated solubility of copper at various pH values and, from that, the relative scale stability. Figure 2 indicates that increasing the pH from approximately 6.6 up to 8.0 should decrease solubility and increase scale stability. Increasing the pH above 8.0 appears to have a negligible effect on copper solubility. It should be noted that Figure 2 shows water with DIC equal to 0.0009 Molar (M), which corresponds to City water with pH 6.6 and alkalinity equal to 60 mg/L as $CaCO_3$. The DIC will change if the water is aerated. Changes in DIC will affect the shape of the curve on Figure 2 slightly, but the ultimate solubility as pH is increased toward 8.0 will remain the same since the effect of hydroxide ligands is dominant over carbonate at the higher pH values.

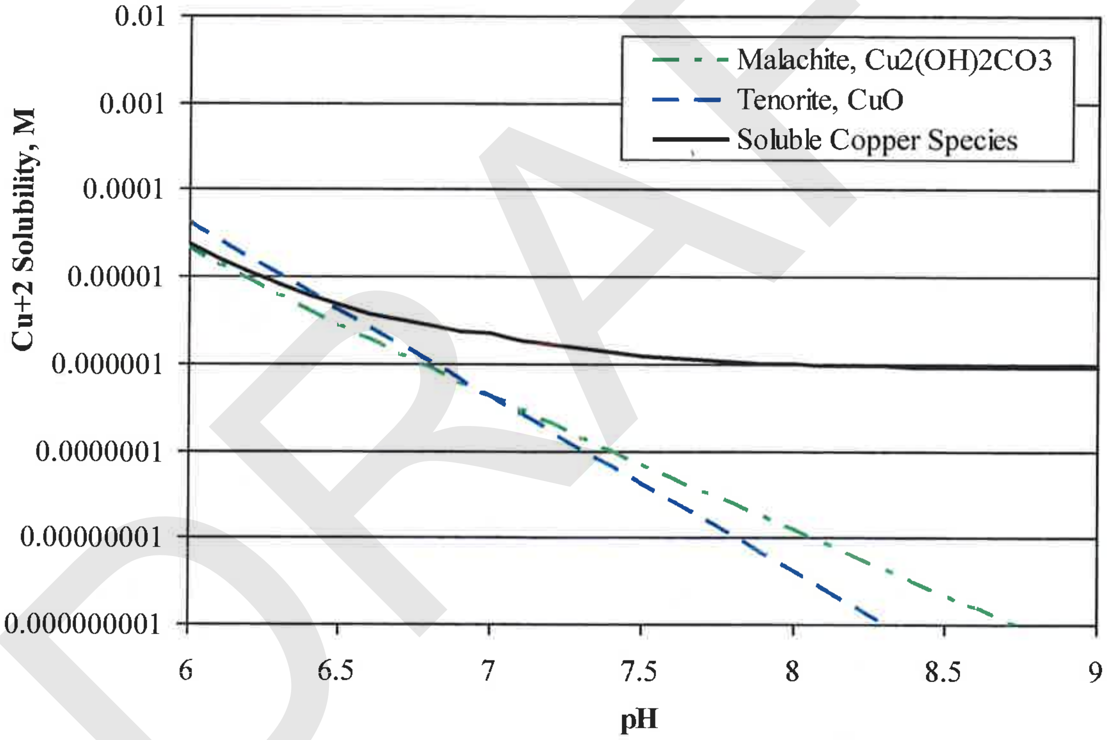

FIGURE 2

Copper Solubility Diagram for Water with DIC = 0.0009 M

For scale stability within the City's distribution system, the data on Figure 2 would suggest that increasing the pH from 6.6 up to and approaching 8.0 should maintain scale stability and decrease levels of soluble copper. This effect continues even as the water approaches pH 8.0 indicating that higher pH levels provide greater benefit.

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Another consideration suggested by Figure 2 is that malachite appears to be less soluble, and therefore likely to be the predominant scale at pH values below 7.0, while tenorite appears to be predominant above pH 7.0. It is conceivable that as the pH in the distribution system is increased when the McAllister Wells are brought online and treated above pH 7.0 that the predominant scale will shift from malachite to tenorite. It is possible that the existing malachite will remain and any new deposition would be tenorite since the solubility of Cu^{+2} predicted by the equilibrium equations is significantly lower for both solids as the pH increases. It is also possible that malachite could dissolve only to redeposit as tenorite. Since the equilibrium characteristics of the two solids are relatively close, i.e., the equilibrium curves on Figure 2 are similar, it is doubtful that copper scale stability will present a water quality issue due to pH changes in the range being considered. The most important information in Figure 2 is the relationship between pH and scale solubility indicating that as pH is increased in the range shown, the copper scales are more stable.

A similar analysis can be done for lead. Although lead has not been a significant water quality compliance consideration for the City, its detrimental health effects warrant an analysis for possible changes due to an increase in pH.

Figure 3 shows the solubility diagram for lead. The two lead solids of interest are cerrusite ($PbCO_3$) and hydrocerrusite ($Pb_3(CO_3)_2(OH)_2$). Another solid, massicot (PbO), was also included in the analysis, but like the copper solids discussed above, it is much more soluble and is not as likely to be present as cerrusite and hydrocerrusite. The lines for cerrusite and hydrocerrusite represent equilibria with the Pb^{+2} ion. Just as with copper, the Pb^{+2} ion will react with hydroxide and carbonate ligands to form soluble complexes. The total soluble lead is shown on the figure.

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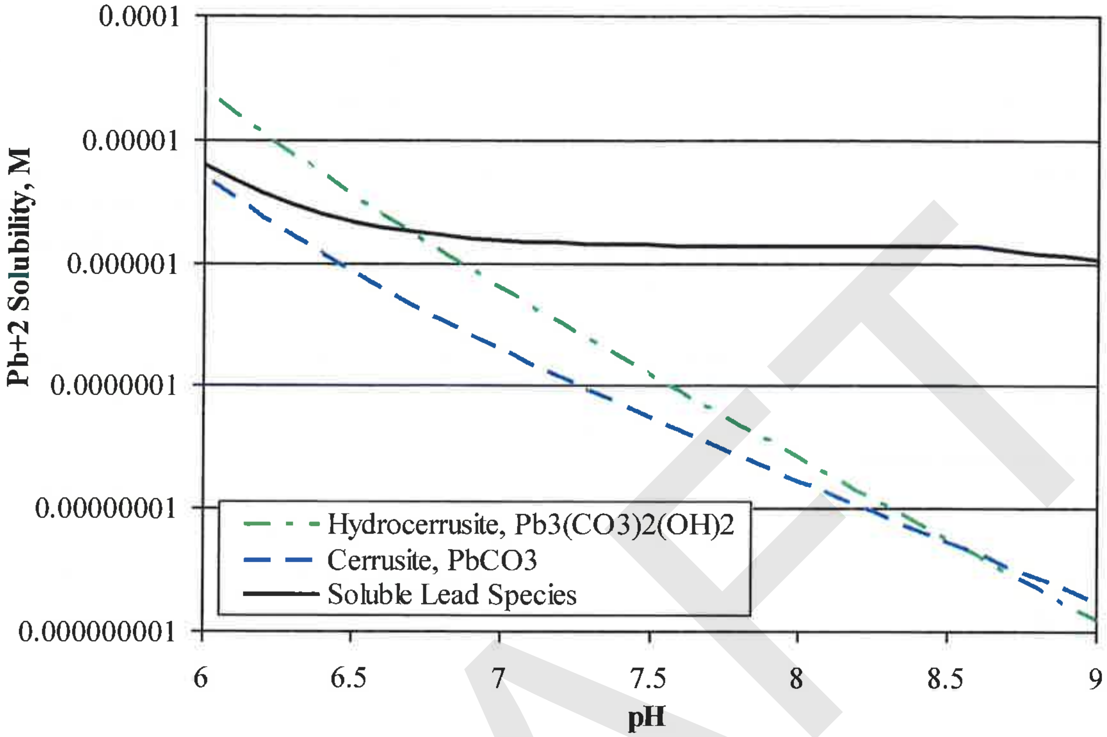

FIGURE 3

Lead Solubility Diagram for Water with DIC = 0.0009 M

The data on Figure 3 indicate that as pH is increased from 6.6 up to 8.0, the solubility of lead decreases slightly. It appears that the predominant scale would be cerrusite for the entire pH range. The equilibrium lines indicate that both cerrusite and hydrocerrusite decrease in solubility as pH is increased. The total amount of soluble lead also decreases, but not as drastically due to lead hydroxide complexes. In short, raising the pH of City water should not cause lead scale dissolution and should decrease future soluble lead levels.

The other metal scale of interest is iron. Iron is a significant component in much of the distribution system and in household plumbing and its release can cause significant issues with taste, odor, color, and particulate. Iron scale can also contain other metals such as arsenic that would be released to drinking water if the scale were to dissolve creating a public health issue (EPA, 2006).

The chemistry of iron scales is very complicated and is much more difficult to represent concisely than copper or lead. Unlike copper and lead where the more oxidized form of the metal is generally present under drinking water conditions, both Fe(II) and Fe(III) can play a role in iron scales. There are multiple iron solids that can be present including multiple solids with the same general chemical formula. For example, FeOOH exists as goethite (α-FeOOH) or lepidocrocite (γ-FeOOH) and each has separate chemistry.

One model of an iron scale system describes it as a multilayered system with Fe(II) compounds prevalent near the pipe wall where the conditions are anoxic and Fe(III) compounds dominating the scale structure at the scale water interface (Sarin, 2004). Generally, Fe(III) compounds tend to be less soluble than Fe(II) compounds. If the water chemistry changes, such as if the water becomes anoxic due to stagnation, the chemistry of the outer layers of the multilayer system can change with Fe(II) compounds becoming dominant and iron can be released.

In addition to complex inorganic chemistry, iron scales can also have a biological element. Several kinds of bacteria are able to use the oxidation of iron as an energy source. Iron bacteria pipe biofilms often have many layers incorporating different iron compounds, sometimes as a slimy, mucous-like layer.

In general, iron compounds have decreased solubility as pH increases in the range in question similar to copper and lead. In addition, pipe loop research has indicated that increasing pH will result in decreasing iron release (Sarin, 2002).

The City already has areas of the distribution system where pH changes are a regular occurrence. In the 298 Zone, McAllister Springs provides the bulk of the water in the zone during the winter months with some contribution from the Allison Springs Wells. The pH in the winter is relatively low and similar to that seen at McAllister Springs. In the summer, the Allison Springs Wells are used more and the average pH of the zone increases. In addition, the Kaiser Well, with its low pH, is also operated during the summer. It is likely that there are localized distribution system areas around the Allison Spring and Kaiser Wells that experience wide pH shifts. The Allison Springs Wells have treated pH values above 7.7 while Kaiser Well produces water with pH 6.4-6.6. The change of pH that occurs at the start of the summer season in the proximity of the Allison Springs Wells would be similar to the system-wide pH increase that would occur if the McAllister Wellfield produces water with pH higher than the existing McAllister Springs. Any water quality changes and associated water quality complaints, if any, that the City has noted during the seasonal change in the 298 Zone will likely be similar to what potentially may be experienced if McAllister Well water were provided at a higher pH.

One thing to note when comparing equilibrium solubility is that the metal concentrations seen in City tap samples may not directly correlate to equilibrium solubility because the system may not be at equilibrium and the City samples probably contain both soluble and particulate metal; the latter present as pieces of scale material entrained in the flow. The equilibria predict only soluble metal. Understanding this limitation, the equilibria analysis is still an excellent tool for predicting scale behavior with water quality changes.

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EXISTING DISTRIBUTION SYSTEM CORROSION CONTROL ANALYSIS

This section examines the water quality of the distribution system, especially the pH, and the copper sampling from recent years. Because the City's lead sampling has indicated lead concentrations that are very low, the corrosion control emphasis will be focused on copper corrosion.

SYSTEM pH

The City samples pH and chlorine residual levels at numerous sample sites throughout the distribution system. In July and August 2012, the City collected over 70 samples. The overall system average pH for this period was 6.92, with a maximum of 7.77 and a minimum of 6.63. Figure 4 shows the average pH per pressure zone. Figure 4 also shows which sources contribute to each zone.

The contributions of the various sources that were used during July and August 2012 are evident in the average pH values for each zone. The majority of the City's source during that period was from McAllister Springs but the contribution of the other sources is significant. For example, the 417 Zone receives water from the Shana Park Well and the Indian Summer Well, which have delivered pH values of 7.5 to 7.6. The addition of these sources to water from the other untreated sources in the zone accounts for the higher pH in that zone. The 338 Zone receives water from the 417 Zone through the 338 Zone Boulevard Reservoir. The 298 Zone receives water from the Allison Springs Well, which also has a higher pH. The addition of high-pH Allison Springs Well water in the 298 Zone is tempered by the addition of Kaiser Well water with a pH of 6.3-6.6.

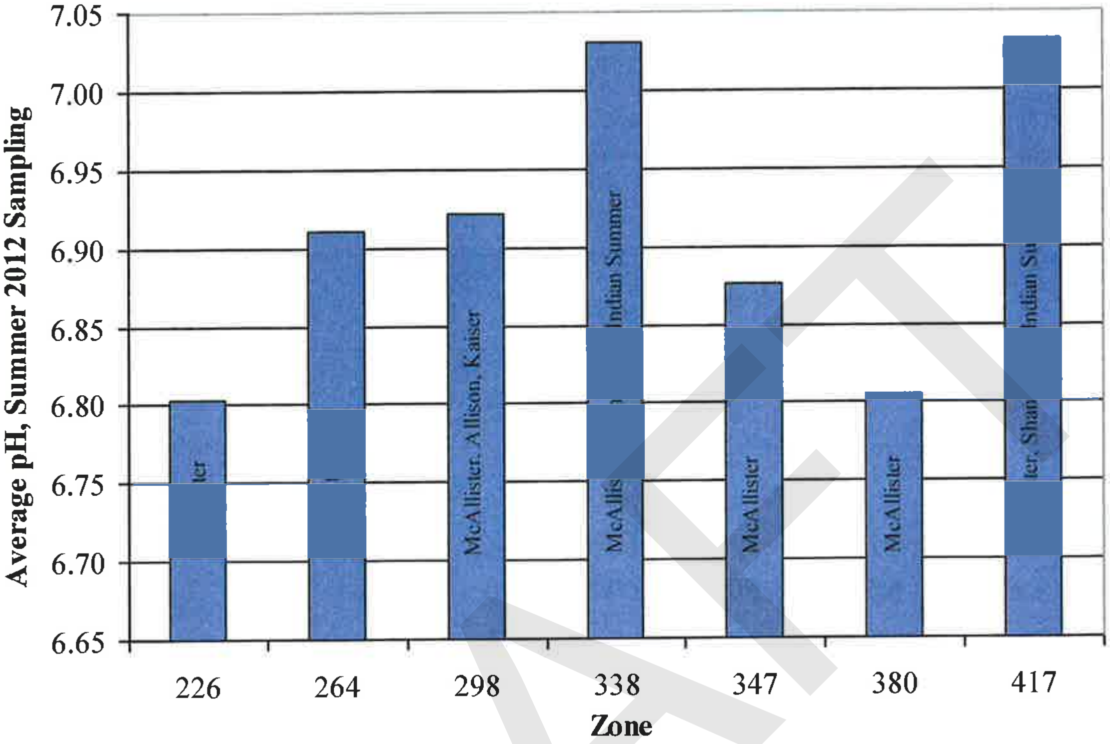

FIGURE 4

Average pH by Zone, July to August 2012

COPPER/pH RELATIONSHIP

The relationship between copper concentrations and pH levels within water systems has been well established and was described above. In general, as pH is increased to the 7.2 to 7.8 pH range for the dissolved inorganic carbon levels seen in City water, the less likely it is that copper will be dissolved and enter the water. This is supported by City copper and pH sampling data.

Copper sampling data has been compared with pH data taken throughout June 2009 and July 2012. The City does not sample for copper and pH at the exact same locations, however, there are numerous sample sites that are near to each other. Figure 5 shows the system distribution of copper concentration versus pH at samples sites less than 1,000 feet apart.

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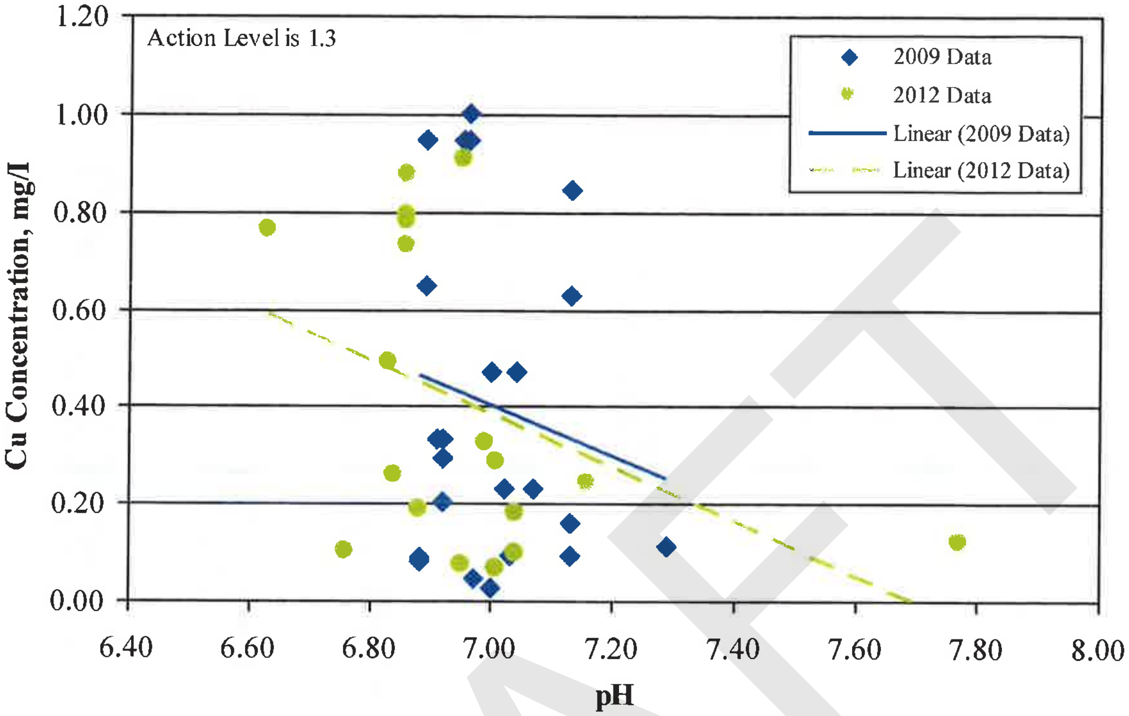

FIGURE 5

Copper Concentration versus pH, 2009 and 2012 Data

Figure 5 shows that there is high variability in the data but that the overall relationship, as shown by the linear trend lines, between copper and pH is inverse; copper concentrations are likely to be higher when pH is lower. Each individual data point is affected by a variety of factors, including source contribution, distribution system piping material, and private plumbing material.

If a comparison of the average copper concentration from all the samples in a particular zone is considered with the average pH of that zone, the relationship between copper and pH is clearer. Comparison of average copper concentration versus average pH by zone at the time of copper sampling is summarized in Table 5 and illustrated on Figure 6.

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TABLE 5

Average Copper, Lead, and pH by Zone

	Copper Average		Lead Average		pH Average	
Zone	**2009**	**2012**	**2009**	**2012**	**2009**	**2012**
226	0.907	0.644	0.004	0.003	6.86	6.80
264	0.191	0.879	0.008	0.003	6.96	6.91
298	0.321	0.327	0.005	0.003	7.14	6.92
338	0.264	0.282	0.002	0.002	7.2	7.03
347	0.400	0.570	0.002	0.005	6.88	6.88
380	0.665	0.701	0.003	0.002	6.9	6.81
417	0.392	0.401	0.002	0.002	6.97	7.03

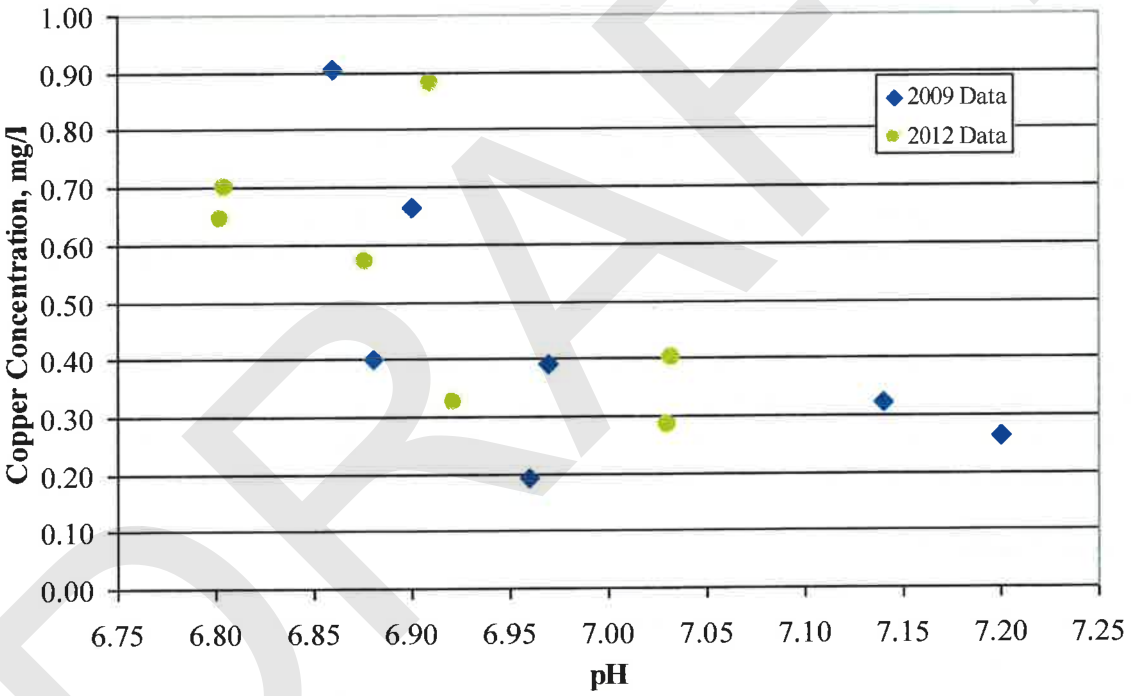

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FIGURE 6

Average Copper, Lead, and pH by Zone

Consolidating sample data as a zonal average provides a clearer depiction of the inverse relationships between copper and pH as shown in Figure 6. The data indicate that copper concentration generally decreases with higher pH.

ASSESSMENT OF POTENTIAL WATER QUALITY CHANGES

To better understand distribution system water quality and the influence of the various sources, a water quality model was used combining two separate modeling schemes. A standard hydraulic model was used to first identify source contribution to various sample locations throughout the system, and then a water quality mixing model was used to verify and predict pH levels at each point under existing and future conditions. The two model components are described below.

City of Olympia Hydraulic Model

The City's water distribution system was hydraulically analyzed using the City's hydraulic model operated by City staff. The model is configured with a graphical user interface. Each model element, including pipes, valves, pumps, and reservoirs, is assigned a unique graphical representation within the program. Each element is also assigned a number of attributes specific to its function. Element attributes include spatial coordinates, elevation, water demand, pipe length, diameter, and pipe status (open/closed), as well as pump, valve, and reservoir characteristics. Model input is accomplished through the creation and manipulation of these objects and their attributes. Model functions include pressure and fire flow, and also extended-period simulation of a variety of water quality parameters. For this analysis, the tracer function was utilized in an extended-period simulation to determine the percent contribution of each source per model node.

City staff ran the model under winter and summer demands and source operation and provided the results to Gray & Osborne. Using historic sample and source data from December 2010 through January 2011 and August 2011, maximum and average contribution per source was determined at the historic data sample locations.

Water Quality Model

Gray & Osborne developed a water quality blending model in Microsoft Excel to predict pH at each sample site based on source contribution and source pH, alkalinity, and water temperature. The model is based on equations established by R. R. Trussell's "Spreadsheet water conditioning" published in the American Water Works Association Journal in 1998.

Model Calibration

The combination of the City's hydraulic model and the water quality blending model was calibrated using existing City water quality data for two periods. A winter period was examined using water quality data and source pumping records from December 2010 and January 2011, and a summer period was examined with information from August 2011. City staff provided hydraulic model results showing contribution by source at each sample location while Gray & Osborne analyzed the expected pH of the source

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contribution at each sample location using the water quality model. Figure 7 shows the water quality sample locations used in both the winter and summer models both for pH and copper sampling.

City staff performed hydraulic model runs for each scenario and entered an average production value for each source based upon the production records for the time period. The average contribution by source was then determined for each of the water quality sampling sites. That data was then entered into the water quality model for each sample location to determine a predicted pH value at that site.

Table 6 provides a comparison of the model-predicted pH and the measured pH for the winter period when only the McAllister and Allison sources were operating.

TABLE 6

Winter Period pH Comparison (McAllister and Allison Operating)

Map No.	Sample Location	Zone	Measured pH	Model pH	pH Difference
1	120 Olympia Avenue NE	226	6.87	6.72	0.15
2	720 Franklin Street SE	226	6.77	6.73	0.04
3	1125 8th Avenue SE	226	6.72	6.71	0.01
24	1077 Franklin Street SE	226	6.76	6.72	0.04
25	310 Quince Street NE	226	6.71	6.72	-0.01
26	Farmer's Market, 700 Capitol Way North	226	6.7	6.72	-0.02
S40	1303 10th Avenue SE	226	6.93	7.77	-0.84
19	1812 Franklin Street SE	264	6.95	6.72	0.23
28	2201 Water Street SW	264	6.91	6.72	0.19
50	1532 Columbia Avenue SW	264	6.85	6.72	0.13
53	1620 Eastside Street SE	264	6.88	6.73	0.15
30	2275 Lakemoor Drive SW	298	7.48	6.73	0.75
61	2629 Montery Street SW	298	7.52	6.71	0.81
66	332 Rogers Street NW	298	7.39	6.72	0.67
S52	1411 Thomas Street NW	298	7.39	6.74	0.65
9	2912 Lybarger Street SE	338	6.93	6.72	0.21
10	1224 Carlyon Avenue SE	338	6.85	6.72	0.13
33	2406 Fir Street SE	338	6.98	6.74	0.24
34	3917 Lakecove Loop SE	338	6.93	6.74	0.19
35	2107 Vista Avenue SE	338	6.92	7.78	-0.86
16	1370 Bigelow Avenue NE	347	6.76	6.72	0.04
36	1021 San Francisco Avenue NE	347	6.76	6.74	0.02
37	Lions Park, 800 Wilson Street SE	347	6.79	6.74	0.05
38	228 McCormick Street NE	347	6.77	6.74	0.03
46	1819 Meixner Street NE	347	6.87	6.73	0.14
52	1614 Quince Street NE	347	6.9	6.73	0.17
8	2812 Conger Avenue NW	380	6.79	6.75	0.04
11	Booster Station, Elliot Avenue NW and Cooper Crest Street NW	380	6.89	6.74	0.15
17	2416 17th Avenue NW	380	6.83	6.74	0.09

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TABLE 6 – (continued)

Winter Period pH Comparison (McAllister and Allison Operating)

Map No.	Sample Location	Zone	Measured pH	Model pH	pH Difference
18	2221 26th Avenue NW	380	6.82	6.75	0.07
29	2717 Walnut Loop NW	380	7.03	6.74	0.29
39	2620 Aztec Drive NW	380	6.89	6.73	0.16
40	1722 Medallion Loop NW	380	6.9	6.72	0.18
51	1611 Easthill Place NW	380	6.83	6.71	0.12
63	303 Kenyon Street NW	380	6.88	6.72	0.16
68	4115 Goldcrest Drive NW	380	7.32	7.79	-0.47
S23	1330 Division Street NW	380	6.88	6.73	0.15
12	2806 Aberdeen Court SE	417	6.81	7.03	-0.22
22	Kasey Keller Drive NE	417	6.82	6.72	0.10
23	3028 60th Avenue SE	417	6.79	6.73	0.06
43	2904 Wilderness Drive SE	417	6.73	6.72	0.01
58	2200 Boulevard Road SE	417	6.75	6.72	0.03
S77	4019 Oriental Drive NE	417	6.68	6.85	-0.17
77	St. Peters Hospital, 413 Lilly Road NE	417	6.86	6.72	0.14
Average			**6.90**	**6.81**	**0.09**

In general, the model reflects the pH trend at each site relatively well. The model generally predicted a slightly lower pH than what was measured. The average delta between the model and what was measured was approximately 0.1 pH units. Since McAllister Springs was the larger contributor during this period, it appears that the pH of water from McAllister Springs may change during storage in reservoirs or through pipe wall interaction in the distribution system. The largest differences occurred in the 298 and 380 Zones. These zones receive the largest contribution from the Allison Springs Well and may reflect localized hydraulic conditions that are not reflected in the model.

Figure 8 shows an average pH by zone for the winter period data. The model predicts the pH trend by zone relatively well, but consistently under-predicts pH by approximately 0.1-0.2 units, except for Zone 298 where the difference is just more than 0.3 units. Since this is the zone into which Allison Springs Well is directed, the difference suggests a model discrepancy. It is possible that the model does not accurately reflect the measured value because the model used an average value for determining the source contribution and the actual source contribution was much higher at the instant of measurement.

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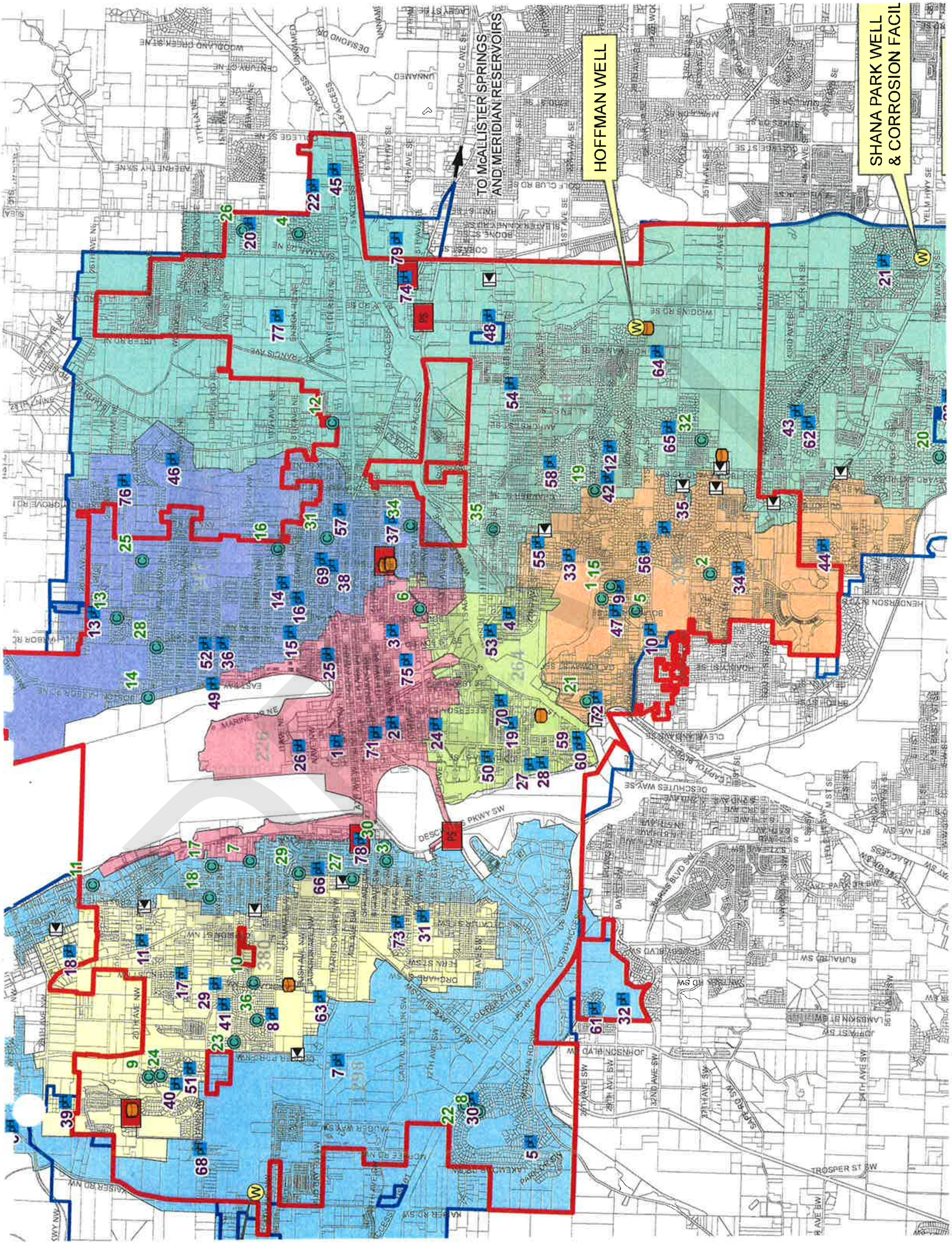
HOFFMAN WELL
SHANA PARK WELL & CORROSION FACIL
TO McALLISTER SPRINGS AND MERIDIAN RESERVOIRS
226
264
338
380
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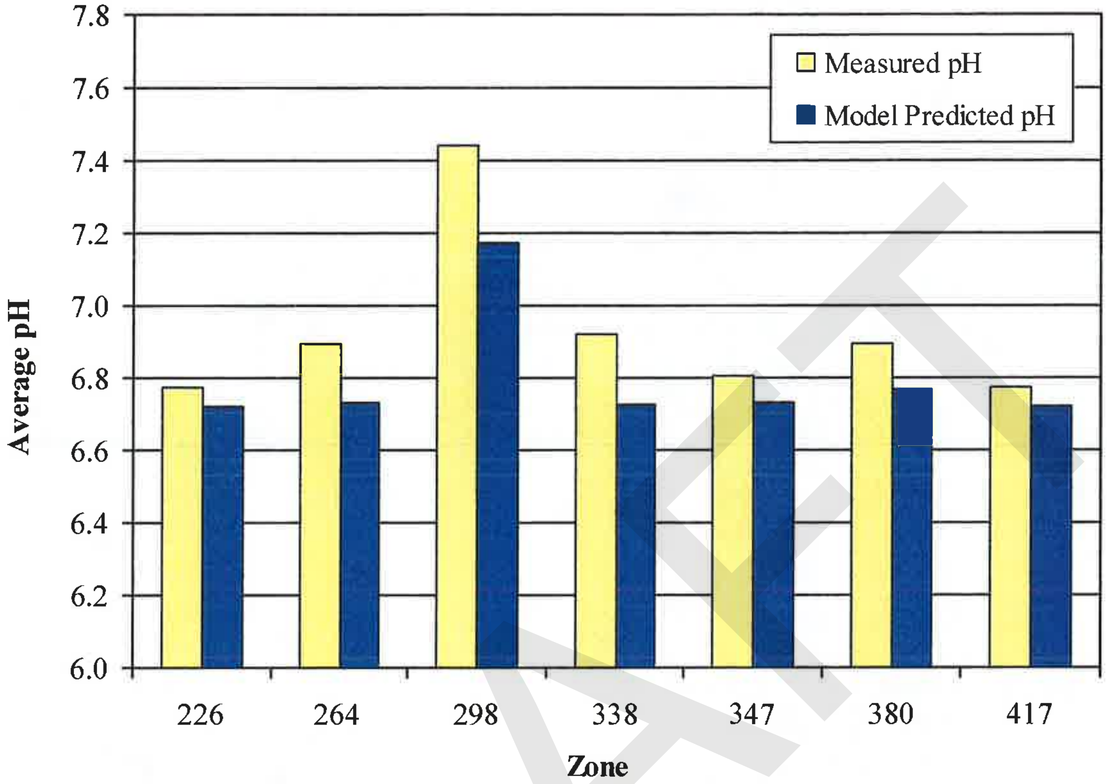

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FIGURE 8

Comparison of Zonal pH Average for Winter Period 2010 to 2011

Table 7 shows a comparison of the model and measured pH during the summer period, when multiple sources were operating.

TABLE 7

Summer Period pH Comparison (McAllister, Shana, Kaiser, Indian Summer, and Allison Operating)

Map No.	Sample Location	Zone	Measured pH	Model pH	pH Difference
1	120 Olympia Avenue NE	226	6.9	6.6	0.3
2	720 Franklin Street SE	226	6.88	6.62	0.26
24	1077 Franklin Street SE	226	6.84	6.61	0.24
25	310 Quince Street NE	226	6.87	7.16	0.23
26	Farmer's Market, 700 Capitol Way North	226	6.85	6.63	0.22
19	1812 Franklin Street SE	264	6.87	6.94	0.24
28	2201 Water Street SW	264	6.88	6.98	0.28
6	2901 Cedrona Drive NW	298	6.91	6.77	0.3
7	Safeway at Cooper Point, 3205 Harrison Avenue NW	298	6.67	6.69	-0.31
30	2275 Lakemoor Drive SW	298	7.17	6.62	0.21
32	2011 Mottman Road (SPSCC)	298	7.19	6.63	0.26
9	2912 Lybarger Street SE	338	7.53	6.62	0.63
10	1224 Carlyon Avenue SE	338	7.65	6.62	0.72
33	2406 Fir Street SE	338	7.69	6.61	0.81
34	3917 Lakecove Loop SE	338	7.63	6.63	0.67
35	2107 Vista Avenue SE	338	7.68	6.6	0.78
44	4525 Village Drive SE	338	7.66	6.64	0.26
14	1652 Yew Street NE	347	6.86	6.63	0.24
15	806 Puget Street NE	347	6.84	6.6	0.21
16	1370 Bigelow Avenue NE	347	6.91	6.61	0.29
36	1021 San Francisco Avenue NE	347	6.84	7.12	0.23
37	Lions Park, 800 Wilson Street SE	347	6.86	6.61	0.23
38	228 McCormick Street NE	347	6.83	7.08	0.2
46	1819 Meixner Street NE	347	7.13	6.93	0.55
8	2812 Conger Avenue NW	380	6.64	7.02	0.01
11	Booster Station, Elliot Avenue NW and Cooper Crest Street NW	380	6.99	6.95	0.48
17	2416 17th Avenue NW	380	6.92	6.61	0.3
18	2221 26th Avenue NW	380	6.91	6.63	0.3
29	2717 Walnut Loop NW	380	6.82	6.63	0.21
31	Decatur Street SW and 10th Avenue SW	380	6.81	6.62	0.2
39	2620 Aztec Drive NW	380	6.87	6.61	0.25
40	1722 Medallion Loop NW	380	6.86	7.62	0.25
12	2806 Aberdeen Court SE	417	7.3	7.58	0.62
43	2904 Wilderness Drive SE	417	7.7	6.64	0.3
45	4330 Martin Way NE	417	6.76	6.58	0.12
Average			**7.05**	**6.77**	**0.32**

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As with the winter data, the model predicts pH values that are generally lower than what was measured at any given site. The average difference between what was measured in the field and what the model calculated during the summer period is approximately 0.3 pH units compared with the 0.1 pH units average difference during the winter period described above. It is possible if there is a process that affects pH in the distribution system piping or storage, that it has a seasonal element related to temperature or another factor.

Figure 9 shows an average pH comparison by zone for the summer data. For most zones, the difference between the average measured pH and the average model-predicted pH is approximately 0.3 pH units. The largest difference is in Zone 338 where the delta was approximately 0.6 pH units. This zone is entirely fed by the 338 Zone Boulevard Reservoir, which receives water from the 417 Zone. It is possible that the hydraulic model does not accurately reflect the actual distribution of water coming from the 417 Zone and that a larger proportion of McAllister Springs water is reflected in the model over the Shana Park and Indian Summer sources. In contrast to the winter data, the summer comparison in the 298 Zone is not significantly different, most likely due to the influence of the Kaiser Well with its pH lower than McAllister Springs.

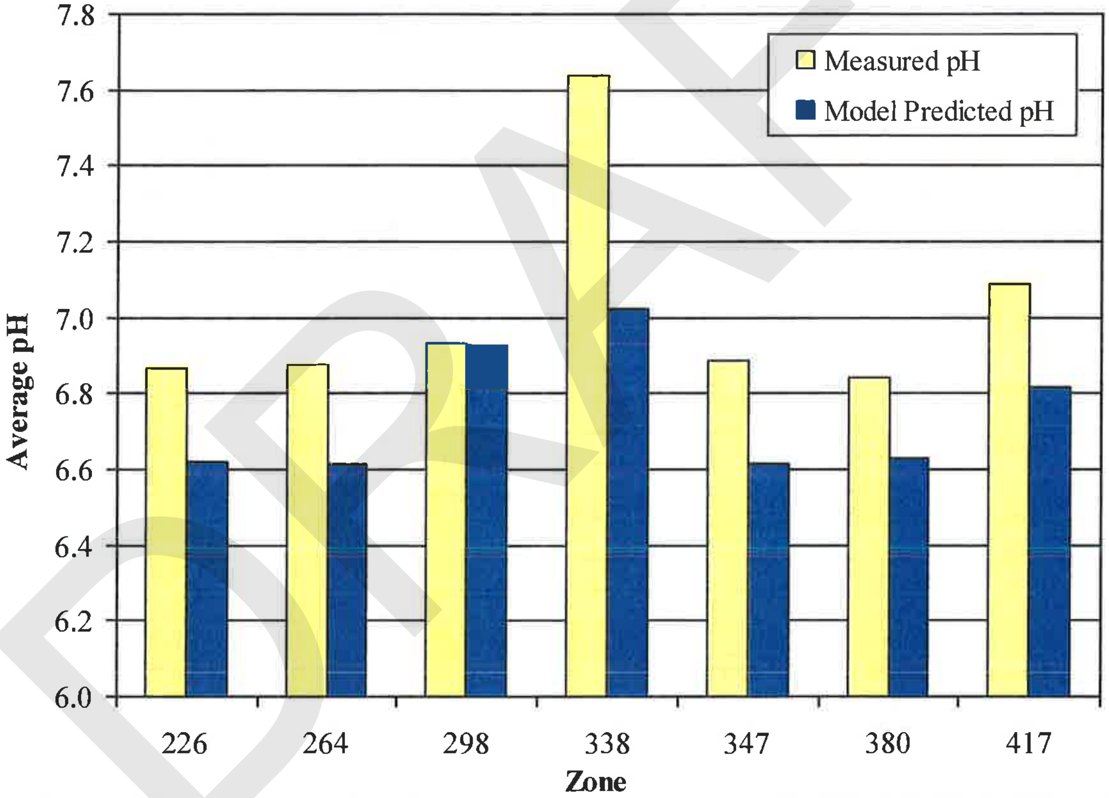

FIGURE 9

Comparison of Zonal Average for Summer Period 2011

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Model Conclusions and Limitations

Even though the model does not precisely reflect the measured conditions, it can be used to provide predictive information about potential changes to water quality from the proposed McAllister Wells. The following limitations apply to using the model for predictive work:

1. The actual pH will likely be higher than the model prediction. The average difference between the model prediction and actual measured value as described above ranged between 0.1 and 0.3 pH units with a larger difference in the summer months. If the difference is related to dissolved carbon dioxide in the water, it is likely that treating the water to remove carbon dioxide and increase pH will have a stabilizing effect and the difference between the model and measured levels would be much less with a McAllister Wellfield source input pH above 7.0.

2. Localized discrepancies may exist in areas where multiple sources with different pH values are contributing to a zone. If the model is used to predict the McAllister Wellfield after treatment, these differences may be less significant as the input pH of the McAllister Wellfield approaches the other treated sources. In the case of the treated McAllister Wellfield, discrepancies in the 298 Zone may still occur in the area around Kaiser Well if the Kaiser Well remained untreated.

POTENTIAL DISTRIBUTION SYSTEM WATER QUALITY CHANGES

One of the goals of developing the hydraulic and water quality models was to predict the effect of pH adjustment at the McAllister Wellfield on the distribution system. For the predictive analysis, the same source proportionality data for winter 2010 to 2011 and summer 2011 that were used for the calibration analysis described above were reused. For each scenario, the water quality for the McAllister Springs water was exchanged with McAllister Well water at example-treated pH values of 7, 7.2, 7.5, and 7.8 with alkalinity of 60 mg/L as $CaCO_3$ to investigate the effect of treated McAllister Wellfield water on average pH by distribution system zone.

The results of modeling for the winter period with the various levels of treated McAllister Wellfield pH are shown on Figure 10. Since only McAllister Wells and the Allison Springs Well are operating, the results are straightforward. In all the zones except the 298 Zone, the average pH of that zone's distribution system is approximately the pH of McAllister water. The minor differences are likely due to temperatures that were recorded at each sample site that were used in the model. For the 298 Zone, the effect of McAllister Well water is tempered by the Allison Springs Well with its pH of 7.7. It should be noted that the model tended to under-predict pH when compared to actual data as described above and shown on Figures 8 and 9. That may be why the value for the

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McAllister Wellfield treated to pH 7.0 in the 298 Zone as shown on Figure 10 is lower than what was measured during the winter of 2010 to 2011.

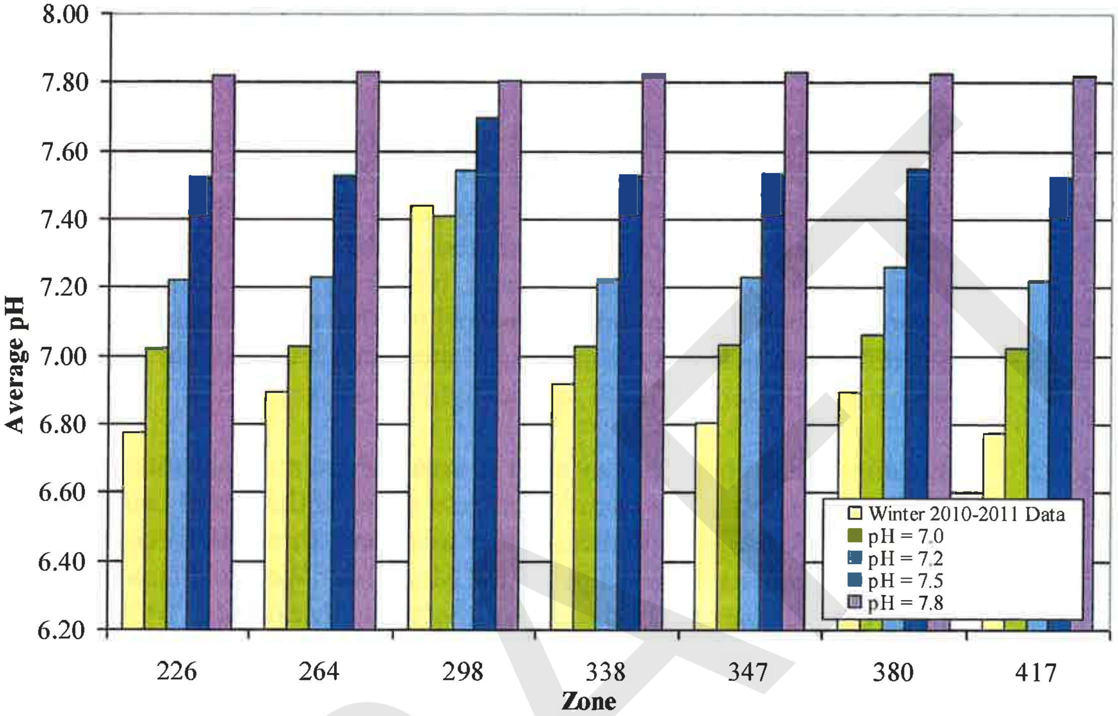

FIGURE 10

Predicted Winter Average pH by Zone for McAllister Well Water Treated to Various pH Levels

A similar analysis is shown on Figure 11 for the summer period. In the 226, 264, 347, and 417 Zones, the effect of treating and adding McAllister Well water is clear with the final pH being just below the treated pH for the well water. For the 298 and 380 Zones, the final pH is significantly below the treated pH for McAllister Well water likely due to the influence of the untreated Kaiser Well. The average pH for treated McAllister water is generally lower in the 338 Zone than what was measured. As noted in the discussion above, the actual measurements in that zone were much higher than what the model predicts likely due a larger influence of Shana Park and Indian Summer Wells than what is reflected in the model.

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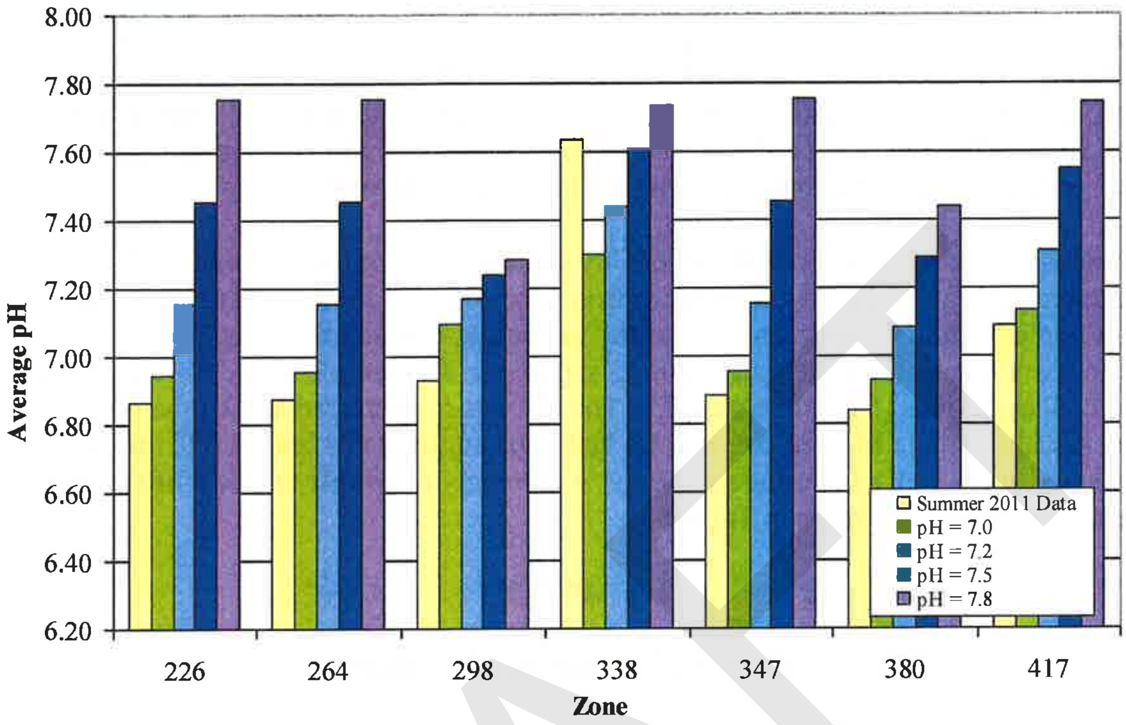

FIGURE 11

Predicted Summer Average pH by Zone for McAllister Well Water Treated to Various pH Levels

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In short, the impact of treatment for McAllister Wells on the distribution system pH is determined by the pH of the treated water.

The model results shown above can also qualitatively illustrate how potential treatment at the Kaiser Well source would affect the 298 Zone. If the McAllister Well sources are treated to a pH comparable to or above the pH at the Allison source (7.7), the Kaiser Well source pH will be substantially lower and its use will depress the pH of the whole 298 Zone, especially locally around the Kaiser source. In order to correct this effect, the pH of the Kaiser source would need to be adjusted to pH 7.5 or at the level of the treated McAllister Wellfield. The Kaiser Well will require treatment if the City wishes to maintain a constant pH throughout the system and optimize corrosion.

Bench-Scale Blending Tests

To verify the results of the water quality blending model and to investigate the effects of blending McAllister Wellfield water after pH adjustment with the other water sources, Gray & Osborne performed a blending test. The blending test was designed to simulate possible mixtures of source water seen in source contribution analysis that the City performed with the hydraulic model.

For the test, three samples of McAllister PW-24 water were taken during the 24-hour test pumping. Two samples were adjusted to pH 7.3, and 7.9, respectively, by sparging with air to remove carbon dioxide. A third sample was adjusted to pH 6.6 to represent raw well water. Because the pH of that sample had increased slightly during storage and transport, the sample was sparged with CO_2 to decrease the pH to 6.6.

Samples were also taken from the other City groundwater sources in January 2013. As indicated above, the samples were taken from a period after the wells had been used so the samples should be representative of the various aquifer sources. The pH of each sample was measured at the source during sampling. The samples were stored in dark and cool conditions (5 to 12 degrees C). The pH was re-measured at the time of the bench-scale testing. Most of the samples had to be adjusted to a level similar to that measured at the well site during sampling. A summary of the pH values of the sources for the mixing test is shown in Table 8.

TABLE 8

Blending Test Source pH Values

Source	Well Site pH	Bench-Scale Test pH	Comments
McAllister PW-24 #1	6.6	6.6	
McAllister PW-24 #2	6.6	7.3	Adjusted with air sparge
McAllister PW-24 #3	6.6	7.9	Adjusted with air sparge
Indian Summer	7.6	7.6	
Shana Park	7.9	7.8	Adjusted with air sparge
Kaiser	6.6	6.6	Adjusted to 6.6 with CO_2 sparge
Allison	7.8	7.8	Adjusted with air sparge

A blending protocol, shown in Table 9, was developed to simulate some representative conditions in the water system. The protocol is designed to simulate the blending in the 298 and 417 zones during the summer and winter seasons. These two zones are the zones into which the other groundwater sources feed. The 50:50 blend with Indian Summer was proposed because of a customer complaint associated with the use of the Indian Summer source.

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TABLE 9

Bench-scale Testing Water Quality Blends

Mixture	Source Percentage					Comment
	McAllister (pH)	Allison	Kaiser	Shana	Indian Summer	
1	10% (6.6)	80%	10%	0	0	298 Zone Summer
2	10% (7.3)	80%	10%	0	0	
3	10% (7.9)	80%	10%	0	0	
4	33% (6.6)	0	0	45%	22%	417 Zone Summer
5	33% (7.3)	0	0	45%	22%	
6	33% (7.9)	0	0	45%	22%	
7	60% (6.6)	40%	0	0	0	298 Zone Winter
8	60% (7.3)	40%	0	0	0	
9	60% (7.9)	40%	0	0	0	
10	50% (6.6)	0	0	0	50%	50:50 Blends with Indian Summer
11	50% (7.3)	0	0	0	50%	
12	50% (7.9)	0	0	0	50%	

For each blend in Table 9, pH, alkalinity, ORP, and chlorine were measured. A qualitative assessment of color, tastes, and odors was also performed.

Since the principal water quality parameter of interest for corrosion control is pH, the pH of the blends as predicted by the water quality blending model and the actual measured pH were compared and the results are shown in Figure 12. The results of the blending tests in Figure 12 indicate that the model does an excellent job of predicting pH within approximately 0.1 pH units.

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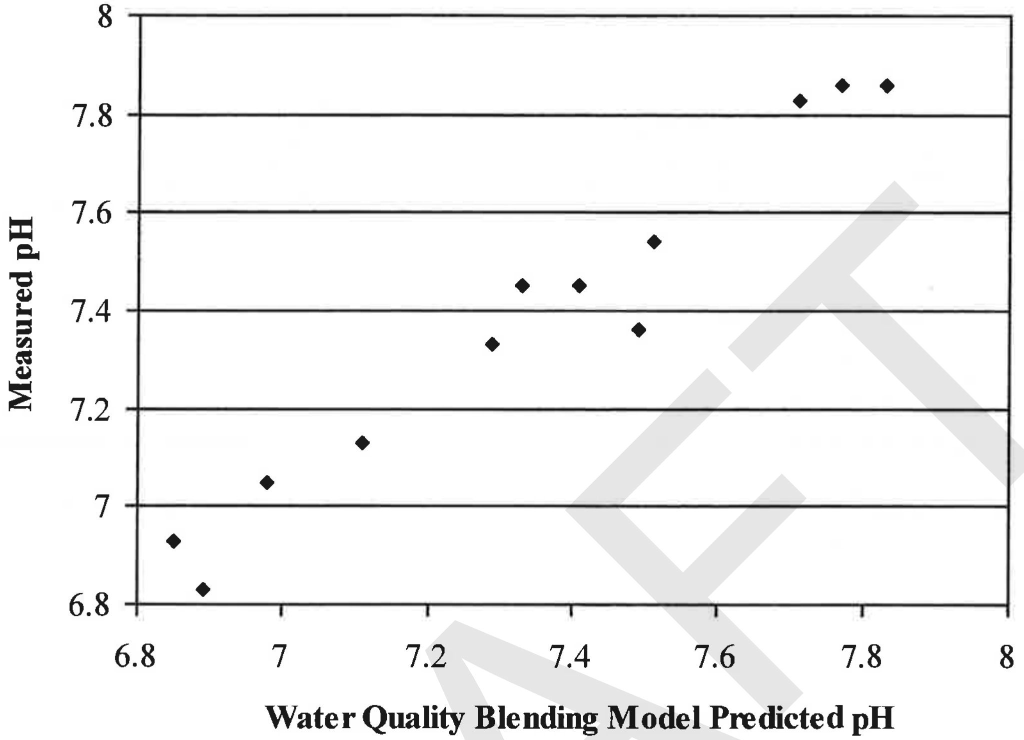

FIGURE 12

Comparison of Predicted and Measured pH Values for the Bench-Scale Blending Study

The blending tests also monitored alkalinity and ORP in the blended samples. Given the relatively small difference between the highest and lowest alkalinities of the source waters, 48 to 60 mg/L as $CaCO_3$, the resulting alkalinity measurements were in a similar range. The results for the ORP measurements were also similar with the ORP measurements for the various blends being similar to the measurements for the sources. In short, the use of McAllister Wellfield water does not appear to pose a significant water quality issue, even with pH adjustment.

Aesthetics

Each of the blends in Table 9 were examined qualitatively for tastes, odors, and colors. No odor or color were detected in any sample. No tastes were noted except for the blends with Indian Summer water, which had a taste or mouth feel that might be described as slick or possibly soapy. While not definitive, the qualitative assessment of the blends with Indian Summer are similar to the nature of customer complaints when the Indian Summer source is operated.

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SUMMARY OF WATER QUALITY AND DETERMINATION OF TARGET PH

The water chemistry discussion above indicates that increasing the pH of the McAllister Wellfield water will decrease metal solubility and, in so doing, decrease corrosion and maintain or increase scale stability. Given the information, a distribution target pH of 7.5 seems reasonable for corrosion control. It is expected that using McAllister Wellfield water instead of McAllister Springs should not be problematic in terms of water quality. In addition, the results of the blending analysis indicate that blending treated McAllister Wellfield water with the City's other sources similar to existing seasonal uses should not create unusual water quality circumstances.

MCALLISTER WELLS CORROSION CONTROL TREATMENT ANALYSIS

This section describes the treatment alternatives for McAllister Wells and the potential influence on distribution system water quality. The section describes the raw water quality, potential treatment alternatives, and expected distribution system effects of each alternative. Based on the analysis detailed previously in this memo, the target pH for the McAllister Wellfield is 7.5 or greater.

MCALLISTER WELL WATER QUALITY

Water quality samples were taken during the test pumping of the McAllister Wellfield Wells in 2012 and 2013 are included in Table 1. The pH of the McAllister Wells can be adjusted by removing carbon dioxide or by adding a strong base to convert carbonic acid to carbonate. The relationship between pH and dissolved carbon dioxide is shown in Table 10 as calculated by Standard Methods 4500. Because there are 395 ppm carbon dioxide in the atmosphere, there is an equilibrium concentration, and therefore, a maximum pH that aeration can achieve. Using a Henry's constant of 0.0046 atm·L/mg at 10 degrees C, the equilibrium CO_2 concentration is 0.9 mg/L. For McAllister Wellfield water, the maximum pH achievable by aeration is expected to be approximately 7.9 to 8.0, a level where approximately 96 percent of carbon dioxide is removed.

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TABLE 10

Relationship Between pH and Carbon Dioxide Removal

pH	Dissolved Carbon Dioxide (mg/L)	Percent Removal (%)
6.6	20.3	0
6.9	10.2	50
7.0	8.1	60
7.1	6.4	68
7.2	5.1	75
7.3	4.0	80
7.4	3.2	84
7.5	2.6	87
7.6	2.0	90
7.7	1.6	92
7.8	1.3	94
7.9	1.0	95
8.0	0.8	96

POTENTIAL TREATMENT TECHNIQUES AND RESULTING WATER QUALITY

Four treatment methods have been evaluated for corrosion control at the McAllister Wellfield. Three treatment techniques involve aeration for carbon dioxide removal: spray nozzles, diffused bubble aeration, and packed tower aeration. Caustic soda addition for pH adjustment has also been considered. These options are described below.

Spray Nozzles/Racks

Spray nozzles/racks are a simple system whereby water enters a reservoir through nozzles above the water surface forming drops. The drops are allowed to fall to the water surface. The headspace of the reservoir may be mechanically vented to remove accumulated carbon dioxide in the headspace of the reservoir. The efficiency of the system depends upon the size of the bubble stream, length of fall, etc. This technology is simple and requires only a modification to the reservoir inlet piping. In Gray & Osborne's experience, spray nozzle systems have been found to be able to remove approximately 60 percent of carbon dioxide. For this analysis, it will be assumed that spray nozzles can achieve a treated pH of 7.0 with 60 percent carbon dioxide removal.

Spray nozzles were discussed in the EES report described earlier. In that report, spray nozzles were analyzed but were not recommended since the spray system that was analyzed was not thought to be able to provide the target pH of 7.5. Because the target

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pH for McAllister Well water will be 7.5 or greater, spray nozzles will not be considered any further in this report.

Diffused Bubble Aeration

Diffused bubble aeration systems use fine-bubble diffusers to introduce air at the base of a water column. The fine bubbles rise through the water column and remove dissolved carbon dioxide. Fine-bubble diffusers are often used to introduce gases into liquids in applications like aeration wastewater processes, but they have been used to remove gases from water. Diffused bubble systems have been reported to remove 65 to 85 percent of carbon dioxide in drinking water applications.

The 1996 EES report recommended diffused bubble aeration as the preferred alternative for treating McAllister Springs water. The report included a pilot study that indicated their pilot equipment could remove 70 to 90 percent of carbon dioxide with air-to-water ratios that were thought suitable for full-scale application.

After the 1996 EES report, EES performed a diffused bubble pilot test using McAllister Spring water and a Baker tank. The 8' W X 35' L X 12' H tank was fitted with 90 ceramic diffusers to test various flow and aeration rates. The pilot apparatus was able to remove carbon dioxide sufficient to elevate the pH to 7.34 to 8.08 depending upon the water and air flow rates. The inlet pH during the pilot test was 6.81 to 7.03, which is significantly higher than the anticipated raw McAllister Wellfield pH of 6.5-6.6. The report recommended installing 4,400 diffusers with 11,000 cfm to treat an average flow of 20 million gallons per day with an expected treated pH of 7.7-7.8.

A closer review of the pilot data indicates that the proposed design may be not be sufficient to remove the desired amount of carbon dioxide. The proposed design used an air to water ratio of approximately 6:1. During the pilot study, the carbon dioxide removal at that air to water ratio was approximately 70 percent, a value that would produce a final treated pH of approximately 7.2 to achieve a treated pH of 7.5 (87 percent removal), the air to water ratio was close to 20:1. Because of the uncertainty of scaling up from pilot to full-scale, the design parameters described below are more conservative than those discussed in the EES pilot.

The diffused bubbler aeration option would be installed within one of the existing Meridian Reservoirs and would be sized to treat 15 mgd initially. The treatment system would include approximately 6,000 membrane diffusers, a control building to house three 5,000 cfm 350-horsepower blowers, and corresponding electrical and telemetry equipment. Two additional blowers would be needed to expand the facility to 23 mgd, though no modifications would be needed to the diffuser system since the airflow per diffuser can be increased from 5 cfm to 8 cfm. Table 11 summarizes the design parameters of the diffused bubbler aerator alternative.

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TABLE 11

Diffused Bubble Aerator Design Parameters

Parameter	Value
Target pH	7.5
Air to Water Ratio	18:1 to 24:1
Air Requirement	
Average Day Production (2028 Projected Demand, 10.9 mgd)	18,020 cfm
Current Peak Production Capacity (15 mgd)	30,000 cfm
Future Peak Production Capacity (23 mgd)	50,000 cfm
Diffusers	
Number	6,000
Air per diffuser, current capacity	5 cfm
Air per diffuser, future capacity	8 cfm
Blowers	
Number, Current Capacity	6
Number, Future Capacity	10
Horsepower, each	350 hp

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Packed Tower Aeration

Packed tower aeration systems are composed of towers with plastic packing. Water is directed to the top of the tower and allowed to cascade down through the packing where it is collected in a sump at the bottom. Air is introduced at the bottom of the packing and forced upward through the packing to exit at the top of the tower. In Gray & Osborne's experience, packed towers are very effective and will remove carbon dioxide to at or near equilibrium. For this analysis, a final pH of 7.8 will be assumed for packed towers assuming that at least 94 percent of dissolved CO_2 can be removed.

The EES report performed a pilot study using packed tower aeration technology. The pilot unit was able to increase the pH of McAllister Springs water to 7.7 consistently.

Packed tower technology has been widely applied to drinking water treatment and there are multiple installations throughout the Northwest. In Gray & Osborne's experience, pilot data from studies such as the 1996 study provide an excellent prediction of full-scale performance. In general, full-scale performance for packed towers is better than pilot studies, thus using a final pH for analysis that is slightly higher than the pilot study is justified.

The proposed packed towers would be located adjacent to the Meridian Reservoirs and would be sized to treat the wellfield's initial daily design flow of 15 mgd. Three packed towers would be constructed initially. There are several construction options for the packed towers. To avoid the need for additional pumps, the packed towers must discharge at a hydraulic grade slightly higher than the overflow of the Meridian

Reservoirs, which is 302 feet. The towers could be designed to discharge via gravity to the Reservoirs by constructing the towers on top of a clearwell. Installing the towers on top of the reservoir was considered, however upon a closer study of the reservoir structure this option has been eliminated. Conversely, the towers could be configured with a sump. Using a sump, the base elevation of the towers could be elevated by either site grading to a higher elevation, or by constructing the towers on top of a platform, either open or filled with soil. The facility would also include a control building to house three 5,400 cfm 10-horsepower blowers and corresponding electrical and telemetry equipment. The wellfield may be expanded to 23 mgd in the future and the clear well would be designed such that a fourth tower could be installed. At that time, a fourth blower would also be installed. Table 12 summarizes the design parameters of the packed tower alternative.

TABLE 12

Packed Tower Aeration Design Parameters

Parameter	Value
Target pH	7.8
Air to Water Ratio	10:1
Air Requirement	
Average Day Production (2028 Projected Demand, 10.9 mgd)	10,120 cfm
Current Peak Production Capacity (15 mgd)	13,930 cfm
Future Peak Production Capacity (23 mgd)	21,350 cfm
Packed Towers	
Number, Current Capacity	3
Number, Future Capacity	4
Dimensions	14 ft diameter, 25 ft tall
Packing Height	15 ft
Liquid Loading Rate	
Current Capacity, three towers	22.6 gpm/sf
Future Capacity, four towers	25.9 gpm/sf
Blowers	
Number, Current Capacity	3
Number, Future Capacity	4
Horsepower, each	10 hp

Sodium Hydroxide (Caustic Soda) Addition

Caustic soda is a strong base that can be also be used to raise the pH of water. A caustic soda feed system would include storage tanks for the caustic soda solution, metering pumps, and injector, a pH analyzer, and control system similar to other chemical feed systems. The caustic soda would be delivered as a liquid in bulk or small-bulk deliveries.

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The dose of caustic soda required to raise the pH to a set level is dependent upon the raw water alkalinity and pH. Assuming a raw water pH of 6.6 and alkalinity of 60 mg/L, a dose of 27 mg/L of 25 percent caustic soda solution would be needed to raise the pH to 7.5.

The caustic soda feed system would be installed within the chlorination facility at the Wellfield. It would be designed for 15 mgd with space to be expanded to 23 mgd. The daily amount of caustic soda required for 15 mgd is 13,510 pounds per day. Two 10,000-gallon double walled polyethylene storage tanks would be needed to store the solution, and a third tank would be needed when the Wellfield is expanded. A static mixer would be installed downstream of the injection point to provide thorough mixing throughout the water stream. The feed pumping system would be flow paced by a signal based upon Wellfield production. A pH analyzer would be included at the facility to verify proper caustic soda feed and to provide an alarm in case of overfeed and high pH. Table 13 summarizes the design parameters of a caustic soda feed system.

TABLE 13

Caustic Soda Feed Design Parameters

Parameter	Value
Target pH	7.5
Average Caustic Soda Dose	27 mg/L
Caustic Soda Solution	25 percent
Caustic Usage by Weight	
Average Day Production (2028 Projected Demand, 10.9 mgd)	9,820 lb/day
Current Peak Production Capacity (15 mgd)	13,510 lb/day
Future Peak Production Capacity (23 mgd)	20,710 lb/day
Caustic Usage by Volume	
Average Day Production (2028 Projected Demand, 10.9 mgd)	940 gal/day
Current Peak Production Capacity (15 mgd)	1,300 gal/day
Future Peak Production Capacity (23 mgd)	1,990 gal/day
Double Walled Storage Tank	
Number, Current Capacity	2
Number, Future Capacity	3
Material	Polyethylene
Volume, each	10,150
Diameter	143 inches/11.9 feet
Height	173 inches/14.4 feet
Feed Pumps	
Average Day Use (2028)	39.2 gph
Current Capacity Peak Day Use	54 gph
Future Capacity Peak Day Use	82.7 gph

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TREATMENT OPTION COMPARISON

In order to evaluate the various options, a variety of factors must be considered, including capital costs, operations costs, lifecycle costs, operation and maintenance issues, and environmental impacts.

Capital Costs

The new packed tower and diffused bubble aerator facilities would be installed on the Meridian Reservoirs site. Both would require a new structure for housing blowers, control equipment, and telemetry. The diffused bubble aerator would be installed within the existing reservoir. As described previously, there are several construction options for the packed towers. Capital costs assume that the stripping towers will be constructed on top of a clearwell.

The caustic soda addition facility would be within the proposed chlorination facility at the Wellfield. It would require an additional 1,000 square feet approximately to house the tanks, piping, metering pumps, and associated electrical and telemetry equipment.

Capital costs for each option are shown in Tables 14, 15 and 16, and detailed cost estimates are included in Appendix A of this report.

TABLE 14

Packed Tower Capital Cost Estimate

Item/Description	Estimated Cost
Mobilization and Demobilization	$184,000
Earthwork and Gravel Materials	$96,000
Packed Towers, Clearwell, Blowers, Piping, and Control Building	$1,386,000
Electrical, Telemetry, and Instrumentation	$350,000
Other	$10,000
Subtotal	**$2,026,000**
State Sales Tax (8.7%)	$177,000
Contingency (20%)	$441,000
Engineering and Administration (25%)	$661,000
Total Estimated Project Cost	**$3,305,000**

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TABLE 15

Diffused Bubble Aeration Capital Cost Estimate

Item/Description	**Estimated Cost**
Mobilization and Demobilization	$148,000
Earthwork and Gravel Materials	$37,000
Diffused Bubbler, Blowers, Piping, and Control Building	$1,081,000
Electrical, Telemetry, and Instrumentation	$350,000
Other	$10,000
Subtotal	**$1,626,000**
State Sales Tax (8.7%)	$141,000
Contingency (20%)	$353,000
Engineering and Administration (25%)	$530,000
Total Estimated Project Cost	**$2,650,000**

TABLE 16

Caustic Soda Addition Capital Cost Estimate

Item/Description	**Estimated Cost**
Mobilization and Demobilization	$54,000
Earthwork and Gravel Materials	$64,000
Building	$275,000
Storage Tanks, Metering Pumps, Piping	$123,000
Electrical, Telemetry, and Instrumentation	$70,000
Other	$10,000
Subtotal	**$596,000**
State Sales Tax (8.7%)	$52,000
Contingency (20%)	$130,000
Engineering and Administration (25%)	$195,000
Total Estimated Project Cost	**$973,000**

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Operation and Maintenance Costs

Operation and maintenance costs, include power, labor, and repair costs. These costs are described in more detail in the following sections for each alternative.

Power Costs

Both aeration treatment options would have costs associated with powering blowers and the controls and telemetry building. Packed towers would also have an additional pumping cost at the wellfield in order to pump water to the higher elevation of the packed towers. Blower and pumping costs are based on projected average day demands for the year 2028, as included in the City's most recent *Water System* Plan. Packed towers would use approximately 90,000 kWh for blowers and 560,000 kWh for additional pumping annually. The diffused bubble aerator would require nearly 8,000,000 kWh annually for blowers. Power costs are shown in Table 17 and are projected forward with inflation.

Caustic soda addition would have insignificant pumping costs associated with the metering pumps. All facilities would have approximately the same annual power requirement for the control building, which is estimated to be approximately 24,000 kilowatt-hours (kWh) per year.

Annual Labor Costs

Both aeration facilities are estimated to require approximately 290 hours of labor each year, which is equivalent to 0.15 full-time employee. The caustic soda feed system would require slightly more labor and is estimated to need 0.2 full-time employees, or 310 labor hours per year. Labor includes monitoring and checking treatment equipment, recording data, and performing any necessary maintenance.

Annual Non-Labor Costs

Annual non-labor costs for all treatment options include repair and maintenance, and the caustic soda system also includes chemical costs.

Annual repair and maintenance material costs can be difficult to estimate; however, one method is to assume full replacement of all mechanical and electrical equipment over the life of the facility. For the aeration options, this includes electrical and control equipment, HVAC, blowers, plumbing, and either aeration towers or diffused bubble aeration system. These costs total $1.235 million and $1.032 million for packed towers and diffused bubble aeration, respectively. The expected life cycle of packed towers and diffused bubble aerators are 50 years and 30 years, respectively. This equates to approximately $25,000 per year for 50 years for packed towers and $35,000 per year for 30 years for diffused bubble aeration. For the caustic soda feed system, the piping, meters, storage tanks, and electrical and telemetry components are included in annual costs. The expected life cycle of the caustic soda feed system is 20 years. This equates to approximately $11,000 per year for 20 years. These costs are shown in Table 17 and projected forward with inflation.

Chemical costs for the caustic soda system are estimated based on projected average day demand in the year 2028, which requires approximately 9,820 lb/day of caustic soda. At a per pound material and delivery cost of $0.20, annual chemical costs are estimated to be approximately $715,000.

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Lifecycle Costs

Lifecycle costs for each facility include the cost of power, and repair and maintenance labor and materials. The packed towers have an expected life of 50 years, the diffused bubble aerator has an expected life of 30 years, and the caustic soda addition system has an expected life of 20 years. In order to compare all options, a 20-year life cycle is used.

Table 17 summarizes the estimates lifecycle costs per treatment option.

TABLE 17

Lifecycle Cost Comparison

	Packed Towers	**Diffused Bubbler**	**Caustic Soda**
Life Cycle Period			
Life Cycle Period Considered - Years	20	20	20
Interest Rates - Recommended rates			
Interest Rate for Capital Investments (Discount Rate) - As %	3.00%	3.00%	3.00%
Wage Inflation Rate - As %	3.00%	3.00%	3.00%
Power Cost Inflation Rate - As %	4.00%	4.00%	4.00%
Interest Rate for Recurring Non-Labor O&M Cost Calculation - As %	2.50%	2.50%	2.50%
Capital Costs			
Initial Capital Investment	**$3,305,000**	**$2,650,000**	**$973,000**
Capital Investment Payoff Period - Years	2	2	2
Capital Investment Payoff - Annual Cash Flow	$1,727,000	$1,385,000	$509,000
Operations and Maintenance Costs - Recurring Annually			
Labor			
Recurring Annual Labor Hours - Operation & Maintenance	288	288	384
Labor Hour Cost, Including Benefits	$50	$50	$50
Annual Recurring Labor Cost	**$14,400**	**$14,400**	**$19,200**
Recurring Non-Labor			
Annual Non-Labor Operations, Equipment & Material Costs	$24,700	$31,100	$725,500
Total Annual Recurring Non-Labor Costs	**$24,700**	**$31,100**	**$725,500**
Power Cost			
Current Power Cost - $/kWhr (2012)	$0.09	$0.09	$0.09
Blower Costs			
Average Quantity Pumped Per Day - cfm	10,120	24,030	
Average Head Pumped Against - psi	0.25	9	
Blower Efficiency	60%	60%	
Annual Hours Blowing Period (2028 ADD)	6,370	6,370	
Horsepower Required	19	1,572	
Annual Blower Power Costs	$8,000	$672,200	
Additional Pumping Costs			
Average Quantity Pumped Per Day - gpm	7,570		
Average Head Pumped Against - ft	43		
Pumping Efficiency	70%		
Annual Hours Pumping Period (2028 ADD)	6,370		
Horsepower Required	118		

TABLE 17 – (continued)

Lifecycle Cost Comparison

	Packed Towers	Diffused Bubbler	Caustic Soda
Annual Pumping Power Costs	$50,400		
Other Power Costs - Annual	**$2,200**	**$2,200**	**$2,200**
Total Annual Power Cost	**$60,600**	**$674,400**	**$2,200**
Summary			
NPV of Capital Investment = Equals Capital Cost	**$3,305,000**	**$2,650,000**	**$973,000**
NPV of Recurring Operations & Maintenance Labor	**$280,000**	**$280,000**	**$373,000**
NPV - Annual Recurring Non-Labor O&M & Power	**$1,750,000**	**$14,953,000**	**$13,503,000**
Life Cycle Net Present Value	**$5,335,000**	**$17,883,000**	**$14,849,000**

NPV = Net Present Value

As seen in Table 17, the lifecycle net present value for diffused bubble aeration is over three times that of packed towers due to much higher annual power costs. The caustic soda addition system has the highest life cycle costs; however, due to the large quantity of caustic soda solution required.

There is the potential for reduced power costs for the diffused bubble aerator if the diffusers are moved up the water column. The water column is assumed to be 20 feet when the reservoir is full. If the diffusers are moved up to a water depth of 15, 10, and 5 feet, power costs would be reduced by approximately 30 percent, 43 percent, and 70 percent, respectively. At 5 feet below overflow, the lifecycle costs for diffused bubble aeration are much closer to those for packed towers. However, it is not certain how the effectiveness of diffused aeration would change for stripping CO_2 and raising pH with a water depth of 5 feet. Additional pilot studies are recommended if diffused bubble aeration is selected to determine how much, if at all, the diffusers could be moved up the water column and still achieve the target pH. Additionally, moving the diffusers up the water column may reduce operational storage within the reservoir, due to the need to maintain adequate water height over the diffusers.

Other Operation and Maintenance Issues

In addition to costs, it is important to consider the details of operating and maintaining each treatment option. Each has potential benefits and disadvantages.

Ease of Maintenance

From a general perspective, packed towers have considerably easier maintenance than diffused bubble aeration. In order to perform any sort of inspection or maintenance on the diffusers, the reservoir would need to be completely drained and then sanitized when refilled. Although similar systems have been designed in wastewater applications to be raised out of the water for maintenance, the practicality of that within the reservoir would be difficult due to limited access and contamination risks. Conversely, with multiple

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packed towers, one can be taken offline for maintenance while the others remain in operation. The caustic soda addition system is the easiest to service out of the three options; however, due to the much smaller scale and component accessibility. Replacement of parts would require the system to be shutdown briefly depending on the component. With multiple tanks and at least two metering pumps, the system could potentially still operate at a limited capacity if any of those elements needed repair. The ease of caustic soda is offset by safety issues since it is a hazardous material and it does present safety issues for City crews that deal with it.

In terms of actual elements that could require repair, the membrane diffuser discs do tend to wear and lose efficiency. In wastewater applications, membrane discs typically have a lifespan of 10 to 20 years. This is expected to be greater in a potable water reservoir since the environment is not as harsh. All elements of the caustic soda system may require more frequent replacement than the other options due to the contact with a chemical.

The source water quality from the McAllister Wellfield does not indicate significant levels of iron or manganese, which are two common elements that can cause fouling and growth in aeration systems. When iron is present in the source water, iron bacteria growth can occur, which requires extensive cleaning. If this occurred, the tower packing material or the membrane diffuser discs would need to be replaced. Replacing the diffuser discs would be more costly and time consuming than replacing the packing material. Fouling is not a consideration with the caustic soda system.

Operational Flexibility

As mentioned above, the packed tower configuration allows one or more towers to be removed from operation and maintain operation in the remaining towers, which provides operational flexibility to match flow rates, perform maintenance, or cycle blowers. There also is some amount of flexibility available to the diffused bubble aeration. The diffusers could be operated only for the period necessary to treat the source water while the well sources are operating, or it could be possible to design the system such that each blower feeds a specific portion of the diffuser grid to allow for cycling of blowers. However, since this application of diffusers is still fairly uncommon, there is still some amount of uncertainty as to the effects of alternate operation schemes on the final pH and CO_2 levels of the water. Since the diffused bubble aeration system would be installed within one of the reservoirs, operation of the system is also depended upon operation of the reservoir. If repairs to the reservoir require it to be drained or taken out of service for an extended period of time, the aeration system will not be operable. The caustic soda feed would be designed to adjust dosage based on source water flow rate. This would optimize the use of caustic soda, but would also require near constant operation. The system would be designed such that individual elements could be taken offline for maintenance while the rest of the system remains operational, though total treatment capacity may be reduced during this time.

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Environmental Impacts

The environmental impact evaluation of each option is based upon power requirements. The diffused aeration system will consume significantly more power each year than the packed towers due to increased blower needs. The caustic soda system does not have significant on-site pump or blower power usage, however the caustic soda manufacturing process requires a significant amount of energy, a cost reflected in the purchase price. Table 18 summarizes estimated annual power requirements for each option.

TABLE 18

Power Requirements

Treatment Option	Annual Power Consumption, kWhr
Packed Towers	672,200
Diffused Bubble Aeration	8,009,200
Caustic Soda Feed	5,939,200

As seen in Table 18, the packed tower requires significantly less power than the other options, thus is determined to have the least environmental impact out of the three treatment options.

Comparison Summary

To summarize the various fields of comparison between the three treatment options, a decision matrix is shown as Table 19. The decision matrix has been developed to evaluate the options using the criteria in a quantitative manner. The matrix includes a weighting factor to allow some criteria to be given more weight than others. Each alternative has been rated for each criterion based on a rating system from 1 (least favorable) to 10 (most favorable). The rating for each criterion is multiplied by the weighting factor to develop a score each criterion. The scores for each criterion are then added together to calculate a total score for each alternative.

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TABLE 19

Decision Matrix

Criteria	Weighting Factor	Packed Towers		Diffused Bubble Aeration		Caustic Soda	
		Rating	Score	Rating	Score	Rating	Score
1. Construction Cost	25	4	100	7	175	9	225
2. O&M Cost	25	9	225	3	75	1	25
3. Effectiveness	15	10	150	7	105	10	150
4. Ease of Maintenance	15	8	120	4	60	6	90
5. Operational Flexibility	10	8	80	5	50	8	80
6. Environmental Impact	10	8	80	4	40	4	40
Total Score	**100**		**755**		**505**		**610**

As seen in Table 19, packed towers is the more desirable option when weighting the areas of comparison.

CORROSION OPTIMIZATION AT INDIAN SUMMER WELL

Because the alkalinity and pH of the Indian Summer well, as shown in Table 1, are similar to the aerated Shana Park and Allison Springs wells, there is no need to treat the Indian Summer well for corrosion control. The pH of the Indian Summer well is 7.56, which is within the 7.5 to 8.0 target in the Water System Plan and in a range where additional pH adjustment may not provide much additional benefit. Consequently, the Indian Summer well should be considered optimized relative to corrosion.

CORROSION OPTIMIZATION AT KAISER WELL

The Kaiser Well pH is significantly different from the Indian Summer Well and the aerated Shana Park and Allison Springs wells. If the McAllister Wellfield is treated, the Kaiser Well pH would also be significantly different from the McAllister Wellfield. The effect of the Kaiser Well on the 298 Zone is significant as predicted in the model analysis above, even when the McAllister Wellfield water is treated to pH 7.8. Since the City operates the Kaiser Well only in the summer, there are areas in the 298 Zone that experience pH swings in the fall and spring as the summer and winter operational schemes are changed. It is possible that the low pH of the Kaiser Well causes increased corrosion and solubility of corrosion scales in the distribution system. Consequently, in order to consider the Kaiser Well optimized for corrosion control, it should be treated to increase pH to a level approximately equal to the other City sources.

PACKED TOWER AERATION

A packed tower aeration system similar to the Shana Park or Allison Springs Wells could be added to the Kaiser Well. Since the Kaiser Well provides water directly to the

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distribution system rather than by way of a storage reservoir, there is no opportunity to use diffused bubble aeration or another in-reservoir means. Table 20 summarizes design parameters of a packed tower at the Kaiser Well.

TABLE 20

Kaiser Well Packed Tower Aeration Design Parameters

Parameter	Value
Target pH	7.5
Air to Water Ratio	10:1
Air Requirement	
Average Day Production (0.22 mgd)	210 cfm
Peak Day Production (0.5 mgd)	470 cfm
Packed Towers	
Number, Current Capacity	1
Dimensions	4 ft diameter, 25 ft tall
Packing Height	15 ft
Liquid Loading Rate	
Average Day Production (0.22 mgd)	12.3 gpm/sf
Peak Day Production (0.5 mgd)	27.9 gpm/sf
Blowers	
Number	1
Horsepower, each	1 hp

The system would include a single tower and a small building to house the blower, pump, and associated electrical and telemetry equipment. Minimal on-site piping revisions would be required as well.

SODIUM HYDROXIDE (CAUSTIC SODA) ADDITION

A second treatment option is to add caustic soda to the source water on-site. Similar to caustic soda feed option for McAllister Wellfield, this system would include a solution storage tank and metering pump and analyzer system. A new building would be required to house the equipment. Kaiser Well is operated for only about three months per year during the summer to supplement flows when demands are high. The capacity of the well is 350 gpm, which would require approximately 720 pounds per day of caustic soda based on an initial pH of 6.38 and an alkalinity of 54 mg/L as $CaCO_3$. A 1,200-gallon tank will provide approximately two weeks of storage. Table 21 summarizes the design parameters for a caustic soda feed system at Kaiser Well.

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TABLE 21

Kaiser Well Caustic Soda Feed Design Parameters

Parameter	Value
Target pH	7.5
Average Caustic Soda Dose	42 mg/L
Caustic Soda Solution	25 percent
Caustic Usage by Weight	
Average Day Production (0.22 mgd)	315 lb/day
Peak Day Production (0.5 mgd)	710 lb/day
Caustic Usage by Volume	
Average Day Production (0.22 mgd)	30 gal/day
Peak Day Production (0.5 mgd)	70 gal/day
Double Walled Storage Tank	
Number	1
Material	Polyethylene
Volume, each	1,200 gallons
Diameter	87 inches/7.25 feet
Height	96 inches/8 feet
Feed Pumps	
Average Day Use	1.2 gph
Peak Day Use	2.9 gph

The caustic soda system would include a small building on-site to house the feed pump and injection piping, along with associated electrical and telemetry equipment. The storage tank will be located adjacent to the building. Minor on-site piping revisions would be needed as well.

TREATMENT OPTION COMPARISON

In order to evaluate the two options, a variety of factors must be considered, including capital costs, operations costs, lifecycle costs, operation and maintenance issues, and environmental impacts.

Capital Costs

As discussed previously, both treatment options at Kaiser Well would include a new building to house electrical, telemetry, and pump equipment. The packed tower and the caustic soda storage tank would be installed adjacent to the building.

Capital costs for each option are shown in Tables 22 and 23, and detailed cost estimates are included in Appendix A of this report.

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TABLE 22

Kaiser Well Packed Tower Capital Cost Estimate

Item/Description	Estimated Cost
Mobilization and Demobilization	$34,000
Earthwork and Gravel Materials	$23,000
Packed Tower, Blower, Pumps, Piping, and Control Building	$209,000
Electrical, Telemetry, and Instrumentation	$100,000
Other	$5,000
Subtotal	**$371,000**
State Sales Tax (8.7%)	$32,000
Contingency (20%)	$81,000
Engineering and Administration (25%)	$121,000
Total Estimated Project Cost	**$605,000**

TABLE 23

Kaiser Well Caustic Soda Addition Capital Cost Estimate

Item/Description	Estimated Cost
Mobilization and Demobilization	$19,000
Earthwork and Gravel Materials	$17,000
Packed Towers, Clearwell, Blowers, Piping, and Control Building	$89,000
Electrical, Telemetry, and Instrumentation	$80,000
Other	$5,000
Subtotal	**$210,000**
State Sales Tax (8.7%)	$18,000
Contingency (20%)	$46,000
Engineering and Administration (25%)	$69,000
Total Project Cost	**$343,000**

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Tables 22 and 23 show the capital cost for the caustic soda addition system are significantly lower than the capital costs for the packed tower alternative.

As an alternative to treatment, the Kaiser Well could be discontinued as a summer source and maintained strictly as an emergency source. This would be possible if the Allison Springs Wells and the McAllister Wellfield have the capacity to compensate for not using the Kaiser Well.

Operation and Maintenance Costs

Operation and maintenance costs, include power, labor, and repair costs. These costs are described in more detail in the following sections for each alternative.

Power Costs

As with the treatment options for McAllister Wellfield, the packed tower option would have costs associated with operating the blower and pump, while the caustic soda system would have insignificant power costs associated with the injection pump. Both would have similar power costs for building operation.

Power costs are shown in Table 24 and are projected forward with inflation.

Annual Labor Costs

Since the Kaiser Well is operated for only several months a year, labor costs will be much less than those for the McAllister Wellfield treatment options. Labor includes monitoring and checking treatment equipment, recording data, and performing any necessary maintenance. Labor costs are shown in Table 24.

Annual Non-Labor Costs

Annual non-labor costs for all treatment options include repair and maintenance, and the caustic soda system also includes chemical costs. Costs are based on the assumption of full replacement of all mechanical and electrical equipment over the life of the facility. For the packed tower, this includes electrical and control equipment, HVAC, blowers, plumbing, and the aeration towers. These costs total $289,000 and $82,000 for packed towers and caustic soda addition, respectively. The expected life cycle of packed towers and caustic soda feed systems are 50 years and 20 years, respectively. This equates to approximately $6,000 per year for 50 years for packed towers and $6,100 per year for 20 years for caustic soda addition. These costs are shown in Table 24 and projected forward with inflation.

Chemical costs for the caustic soda system are estimated based on full well capacity of 360 gpm, which requires approximately 730 lb/day of caustic soda. Assuming a material and delivery cost of $0.20/pound, annual chemical costs are estimated to be approximately $17,600.

Lifecycle Costs

Lifecycle costs for each facility include the cost of power, and repair and maintenance labor and materials. The packed towers have an expected life of 50 years and the caustic soda addition system has an expected life of 20 years. In order to compare both options, a 20-year life cycle is used.

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Table 24 summarizes the estimates lifecycle costs per treatment option.

TABLE 24

Kaiser Well Lifecycle Cost Comparison

	Packed Towers	Caustic Soda
Life Cycle Period		
Life Cycle Period Considered - Years	20	20
Interest Rates - Recommended rates		
Interest Rate for Capital Investments (Discount Rate) - As %	3.00%	3.00%
Wage Inflation Rate - As %	3.00%	3.00%
Power Cost Inflation Rate - As %	4.00%	4.00%
Interest Rate for Recurring Non-Labor O&M Cost Calculation - As %	2.50%	2.50%
Capital Costs		
Initial Capital Investment	**$605,000**	**$343,000**
Capital Investment Payoff Period - Years	2	2
Capital Investment Payoff - Annual Cash Flow	$316,000	$179,000
Operations and Maintenance Costs - Recurring Annually		
Labor		
Recurring Annual Labor Hours - Operation & Maintenance	55	69
Labor Hour Cost, Including Benefits	$50	$50
Annual Recurring Labor Cost	**$2,800**	**$3,500**
Recurring Non-Labor		
Annual Non-Labor Operations, Equipment & Material Costs	$6,000	$24,200
Total Annual Recurring Non-Labor Costs	**$6,000**	**$24,200**
Power Cost		
Current Power Cost - $/kWhr (2012)	$0.09	$0.09
Blower Costs		
Average Quantity Pumped Per Day - cfm	470	
Average Head Pumped Against - psi	0.25	
Blower Efficiency	60%	
Annual Hours Blowing Period	2,208	
Horsepower Required	1	
Annual Blower Power Costs	$130	
Additional Pumping Costs		
Average Quantity Pumped Per Day - gpm	350	
Average Head Pumped Against - ft	43	
Pumping Efficiency	70%	
Annual Hours Pumping Period (2028 ADD)	2,208	
Horsepower Required	5	
Annual Pumping Power Costs	$800	
Other Power Costs - Annual	**$2,200**	**$2,200**
Total Annual Power Cost	**$3,100**	**$2,200**
Summary		
NPV of Capital Investment = Equals Capital Cost	**$605,000**	**$343,000**
NPV of Recurring Operations & Maintenance Labor	**$54,000**	**$68,000**
NPV - Annual Recurring Non-Labor O&M & Power	**$177,000**	**$496,000**
Life Cycle Net Present Value	**$836,000**	**$907,000**

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As seen in Table 24, the lifecycle net present value for a packed tower is slightly less than that for the caustic soda addition system.

Other Operation and Maintenance Issues

In addition to costs, it is important to consider the details of operating and maintaining each treatment option. Each has potential benefits and disadvantages.

Ease of Maintenance

The caustic soda addition system is the easiest to service out of the two options, due to the smaller scale and component accessibility. However, the ease of caustic soda maintenance is offset by safety issues since it is a hazardous material and it does present safety issues for City crews that deal with it.

In terms of actual elements that could require repair, all elements of the caustic soda system may require more frequent replacement than packed tower components due to the contact with a chemical. Packed tower components that may require more frequent repair are the pump and blower, for which maintenance is relatively simple.

The Kaiser Well has had elevated levels of iron or manganese in the past, which are two common elements that can cause fouling and growth in aeration systems. When iron is present in the source water, iron bacteria growth can occur, which requires extensive cleaning. If this occurred, the tower packing material would need to be replaced. Fouling is not a consideration with the caustic soda system.

Operational Flexibility

Neither treatment option has the ability for any component to be taken off-line for maintenance and still allow the system to operate. However, due to the relatively low production and seasonal nature of operating the Kaiser Well, this is not a serious concern.

Kaiser Well typically produces water a constant flow rate, thus the treatment systems do not need to be designed for a wide range of flows, which improves efficiency. However, if flow rates do fluctuate, the caustic soda feed system would be designed to adjust the dosage based on actual flow rate, making it slightly more efficient than the packed tower.

Environmental Impacts

The environmental impact evaluation for each option is based on power requirements. The caustic soda system does not have significant on-site pump or blower power usage, as with a packed tower, however the manufacturing process requires a significant amount of energy. Table 25 summarizes estimated annual power requirements for each option.

TABLE 25

Power Requirements

Treatment Option	Annual Power Consumption, kWhr
Packed Towers	69,800
Caustic Soda Feed	172,600

As seen in Table 25, the packed tower requires significantly less power than the other options, thus is determined to have the least environmental impact out of the two treatment options.

Comparison Summary

A decision matrix is shown as Table 26 to compare the two options across the various fields discussed.

TABLE 26

Kaiser Well Decision Matrix

Criteria	Weighting Factor	Packed Towers		Caustic Soda	
		Rating	Score	Rating	Score
1. Construction Cost	25	4	100	9	225
2. O&M Cost	25	9	225	5	125
3. Effectiveness	15	10	150	10	150
4. Ease of Maintenance	15	8	120	6	90
5. Operational Flexibility	10	6	60	7	70
6. Environmental Impact	10	8	80	5	50
Total Score			**735**		**710**

As seen in Table 26 the two options have very close weighted total scores.

CONCLUSIONS AND RECOMMENDATIONS

The information discussed in this report yields the following conclusions:

1. McAllister Wellfield water is expected to be very similar to McAllister Springs water with respect to inorganic constituents and alkalinity. The pH at the wellhead appears to be equal to, or slightly below, that measured in McAllister Springs. The substitution of McAllister Well water for McAllister Spring water is expected to cause no significant water quality changes, with exception of pH adjustment for corrosion control.

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2. Copper and lead solubility equilibria analysis indicate that scale stability and metal solubility will decrease if the pH of McAllister Wellfield water is increased above the current 6.6 to 6.7 pH historically measured at McAllister Springs. The marginal decrease in solubility for lead lessens as the pH approaches 8.0, while the marginal decrease in copper solubility lessens as the pH approaches 8.5. While the chemistry of iron solids is not as simple as for copper and lead, an increase in pH is expected to result is more stable iron compounds and less iron release. In general, adjusting McAllister Wellfield water to a pH higher than the existing McAllister Springs level is expected to provide a positive effect on solubility and maintain the existing scale stability with little metal release.

3. The City of Olympia distribution system exhibits definite pH trends reflecting the contributions of the various sources based on the analysis of the 2010 to 2011 data. During the winter months, the water quality in the system was very similar to the McAllister Springs water quality except for the 298 Zone, which had a higher pH from the contribution of the Allison Springs Well. During the summer months, the influence of McAllister Springs was dominant in the 226, 264, 347, and 380 Zones. The influence of McAllister Springs was tempered in the 417 and 298 Zones by the contributions of the other well sources. The 338 Zone also indicated contributions from other sources, likely because it is fed from the 417 Zone through the Boulevard Reservoir.

4. City of Olympia data indicate that there is a correlation between the average pH in a zone and the average copper level, although this trend is less evident with individual data points. Copper levels in zones with low measured pH were higher than copper levels in zones with average pH measurements above 7.0.

5. The combination of the City's hydraulic and Gray & Osborne's water quality model generally predicted lower pH values than what has been historically measured, but was indicative of trends seen during the 2010 to 2011 period during which water quality was analyzed. The combined water models were used to predict the effects of adding McAllister Wellfield water at various pH values.

It is our recommendation that the working target pH in the distribution system be 7.5 or greater. This is similar to past recommendations and is justified from historical water quality data and water quality analysis. Providing treated water at an approximate minimum pH of 7.5 will match the pH of the sources, with the exception of the Kaiser source, and minimize seasonal or local variations in pH that could affect scale stability and the unanticipated consequences of scale instability. Providing McAllister Wellfield water with pH 7.5 or greater should also maintain existing scale stability and provide optimized corrosion control for lead and copper.

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Either diffused aeration, packed tower aeration, or caustic soda addition should provide the necessary pH adjustment. When comparing the three, packed tower aeration is well understood and applied, has a lower lifecycle cost, lower annual operating cost, but a higher initial capital cost while the other options have lower capital costs but higher operating costs. Packed tower aeration has the added benefit that City staff is already familiar with Shana Park and Allison Springs Wells where the technology has been successfully applied. Given the life cycle cost advantage and the successful application in other City sources, Gray & Osborne recommends that packed tower aeration be pursued for McAllister Wellfield corrosion control.

The Indian Summer Well can be considered optimized for corrosion control since it has a pH of 7.6 without treatment. This value is already above the target pH of 7.5 for the distribution system.

The Kaiser Well will require treatment for corrosion control optimization since its 6.4 pH is substantially lower than 7.5 and its influence in the 298 and 380 Zones is evident in the distribution system analysis. This report analyzed packed tower aeration and caustic soda addition to treat the Kaiser Well to a pH of 7.5. The two treatment systems ranked very closely when comparing the two. Although packed tower has a higher capital cost, operation and maintenance costs are less than that for a caustic soda feed system. As a result, a packed tower is the recommended treatment option for the Kaiser Well if it is to remain in regular use. As an alternative, the Kaiser Well could be declared an emergency source and left untreated.

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EXHIBIT A

DETAILED COST ESTIMATES

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City of Olympia
McAllister Wellfield - Corrosion Control Facility (Packed Tower w/ 12' Clearwell)
Preliminary Cost Estimate

NO	DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT
1	Mobilization and Demobilization	1 LS	$ 184,200	$ 184,200
2	Excavation, Backfill, Compaction	1 LS	$ 60,000	$ 60,000
3	Special Excavation	40 CY	$ 60	$ 2,400
4	Trench Safety System	1 LS	$ 8,000	$ 8,000
5	Gravel Base	335 TN	$ 40	$ 13,400
6	Gravel Backfill for Rigid Pipe	185 CY	$ 20	$ 3,700
7	Foundation Gravel	95 TN	$ 40	$ 3,800
8	Structural Fill	225 TN	$ 20	$ 4,500
9	Piping, Valves, and Appurtenances	1 LS	$ 250,000	$ 250,000
10	Reinforced Concrete	240 CY	$ 1,000	$ 240,000
11	10 hp Blower	3 EA	$ 7,000	$ 21,000
12	Aeration Tower	3 EA	$ 200,000	$ 600,000
13	Electrical	1 LS	$ 200,000	$ 200,000
14	Telemetry and Instrumentation	1 LS	$ 150,000	$ 150,000
15	CMU Aeration Facility Building (1,000 SF @ $275/SF)	1 LS	$ 275,000	$ 275,000
16	Testing, Commissioning, Training	1 LS	$ 10,000	$ 10,000
	Subtotal			$ 2,026,000
	Washington State Sales Tax (8.7%)			$ 176,262
	Subtotal			$ 2,202,262
	Contingency (20%)			$ 440,452
	Total Estimated Construction Cost			**$ 2,643,000**
	Engineering and Administrative Costs (25%)			$ 660,750
	Total Project Cost			**$ 3,303,750**

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City of Olympia
McAllister Wellfield - Corrosion Control Facility (Diffused Bubble Aeration)
Preliminary Cost Estimate

NO	DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT
1	Mobilization and Demobilization	1 LS	$ 147,700	$ 147,700
2	Excavation, Backfill, Compaction	1 LS	$ 30,000	$ 30,000
3	Special Excavation	10 CY	$ 60	$ 600
4	Trench Safety System	1 LS	$ 2,000	$ 2,000
5	Foundation Gravel	55 TN	$ 40	$ 2,200
6	Structural Fill	95 TN	$ 20	$ 1,900
7	Piping, Valves, and Appurtenances	1 LS	$ 150,000	$ 150,000
8	350 hp Blower	6 LS	$ 30,000	$ 180,000
9	Membrane Disc Aeration System	1 LS	$ 338,000	$ 338,000
10	Electrical	1 LS	$ 200,000	$ 200,000
11	Telemetry and Instrumentation	1 LS	$ 150,000	$ 150,000
12	CMU Aeration Facility Building (1,500 SF @ $275/SF)	1 LS	$ 412,500	$ 412,500
13	Testing, Commissioning, Training	1 LS	$ 10,000	$ 10,000
	Subtotal			$ 1,624,900
	Washington State Sales Tax (8.7%)			$ 141,366
	Subtotal			$ 1,766,266
	Contingency (20%)			$ 353,253
	Total Estimated Construction Cost			**$ 2,120,000**
	Engineering and Administrative Costs (25%)			$ 530,000
	Total Project Cost			**$ 2,650,000**

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City of Olympia
McAllister Wellfield - Corrosion Control Facility (Caustic Soda)
Preliminary Cost Estimate

NO	DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT
1	Mobilization and Demobilization	1 LS	$ 54,000	$ 54,000
2	Excavation, Backfill, Compaction	1 LS	$ 60,000	$ 60,000
3	Special Excavation	10 CY	$ 60	$ 600
4	Foundation Gravel	50 TN	$ 40	$ 2,000
5	Structural Fill	80 TN	$ 20	$ 1,600
6	Piping, Valves, and Appurtenances	1 LS	$ 25,000	$ 25,000
7	Metering Pumps	2 EA	$ 25,000	$ 50,000
8	10,000 Gallon Tank	2 EA	$ 24,000	$ 48,000
9	Electrical, Telemetry, and Instrumentation	1 LS	$ 70,000	$ 70,000
10	CMU Building (1,000 @ $275/SF)	1 LS	$ 275,000	$ 275,000
11	Testing, Commissioning, Training	1 LS	$ 10,000	$ 10,000
	Subtotal			$ 596,200
	Washington State Sales Tax (8.7%)			$ 51,869
	Subtotal			$ 648,069
	Contingency (20%)			$ 129,614
	Total Estimated Construction Cost			**$ 777,700**
	Engineering and Administrative Costs (25%)			$ 194,425
	Total Project Cost			**$ 972,125**

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City of Olympia
Kaiser Well - Corrosion Control Facility (Packed Tower)
Preliminary Cost Estimate

NO	DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT
1	Mobilization and Demobilization	1 LS	$ 33,600	$ 33,600
2	Excavation, Backfill, Compaction	1 LS	$ 15,000	$ 15,000
3	Trench Safety System	1 LS	$ 1,000	$ 1,000
4	Gravel Base	100 TN	$ 40	$ 4,000
5	Gravel Backfill for Rigid Pipe	60 CY	$ 20	$ 1,200
6	Foundation Gravel	20 TN	$ 40	$ 800
7	Structural Fill	40 TN	$ 20	$ 800
8	Piping, Valves, and Appurtenances	1 LS	$ 50,000	$ 50,000
9	20 hp Pump	1 EA	$ 8,000	$ 8,000
10	1 hp Blower	1 EA	$ 3,000	$ 3,000
11	Aeration Tower	1 EA	$ 120,000	$ 120,000
12	Electrical	1 LS	$ 50,000	$ 50,000
13	Telemetry and Instrumentation	1 LS	$ 50,000	$ 50,000
14	CMU Aeration Facility Building (100 SF @ $275/SF)	1 LS	$ 27,500	$ 27,500
15	Testing, Commissioning, Training	1 LS	$ 5,000	$ 5,000
	Subtotal			$ 369,900
	Washington State Sales Tax (8.7%)			$ 32,181
	Subtotal			$ 402,081
	Contingency (20%)			$ 80,416
	Total Estimated Construction Cost			**$ 483,000**
	Engineering and Administrative Costs (25%)			$ 120,750
	Total Project Cost			**$ 603,750**

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City of Olympia
Kaiser Well - Corrosion Control Facility (Caustic Soda)
Preliminary Cost Estimate

NO	DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT
1	Mobilization and Demobilization	1 LS	$ 19,100	$ 19,100
2	Excavation, Backfill, Compaction	1 LS	$ 10,000	$ 10,000
3	Special Excavation	5 CY	$ 60	$ 300
4	Trench Safety System	1 LS	$ 2,000	$ 2,000
5	Gravel Base	55 TN	$ 40	$ 2,200
6	Gravel Backfill for Rigid Pipe	30 CY	$ 20	$ 600
7	Foundation Gravel	15 TN	$ 40	$ 600
8	Structural Fill	40 TN	$ 20	$ 800
9	Piping, Valves, and Appurtenances	1 LS	$ 20,000	$ 20,000
10	Metering Pumps	1 EA	$ 10,000	$ 10,000
11	1,200 Gallon Tank	1 EA	$ 4,000	$ 4,000
12	Electrical, Telemetry, and Instrumentation	1 LS	$ 80,000	$ 80,000
13	CMU Building (200 SF @ $275/SF)	1 LS	$ 55,000	$ 55,000
14	Testing, Commissioning, Training	1 LS	$ 5,000	$ 5,000
	Subtotal			$ 209,600
	Washington State Sales Tax (8.7%)			$ 18,235
	Subtotal			$ 227,835
	Contingency (20%)			$ 45,567
	Total Estimated Construction Cost			**$ 274,000**
	Engineering and Administrative Costs (25%)			$ 68,500
	Total Project Cost			**$ 342,500**

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APPENDIX C

TECHNICAL MEMO DESIGN COMPILATION

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MEMORANDUM

TO: Tim Richardson, P.E.
City of Olympia
FROM: Mike Johnson, P.E.
Joe Plahuta, P.E.
DATE: February 14, 2014
SUBJECT: Blower Location Alternatives Memo
G&O PROJECT NO: 12225.07

BACKGROUND

The City of Olympia is constructing a packed tower aeration corrosion control facility to increase the pH of the water produced by the McAllister Wellfield. The facility will initially consist of three packed tower units to treat the initial total wellfield flow rate of 10,500 gpm. A fourth tower unit will be added in the future to treat the ultimate wellfield production capacity of 16,000 gpm.

Initially, air will be supplied to the packed tower units from three centrifugal blowers with an output of approximately 5,500 cubic feet per minute (cfm) each for a total air flow rate of 16,500 cfm. A fourth blower will be added coincident with construction of the fourth packed tower to provide a total airflow rate 22,000 cfm. The discharge from these blowers will be routed to a distribution manifold connecting the air inlets on each tower.

The purpose of this memo is to describe and evaluate different options for locating the aforementioned blowers. The alternatives evaluated are listed below:

Alternative 1: Locate blowers outside adjacent to the packed towers.

Alternative 2: Locate the blowers in the existing Meridian Valve House.

Alternative 3: Locate the blowers in a new 432 square foot CMU building.

DESCRIPTION AND EVALATION OF ALTERNATIVES

Alternative 1: Locate Blowers Outside Adjacent to the Packed Towers

This alternative would locate the blowers outside, adjacent to the packed towers. The blowers would be mounted to the same concrete pad as the packed towers. Air would be drawn into the blowers through a filter and discharged to 36-inch diameter duct connecting the tower air inlets and blower discharge to a common manifold. Each of the blowers would be connected to the manifold through a segment of vertical ductwork equipped with a backdraft damper. The motor starters and control equipment associated with this alternative would be located in the existing valve house. Figure 1 shows an elevation view of the proposed blower configuration.

An advantage of this alternative is that all systems are located above grade, simplifying maintenance and reducing the likelihood of conflict with existing utilities. The primary disadvantage of this alternative is that the blowers are located outside, reducing noise attenuation and leaving the blower units exposed to the weather.

Alternative 2: Locate the Blowers in the Existing Meridian Valve House

This alternative would locate the blowers in the existing Meridian Valve House. The blowers could either be installed in the middle room on the top floor of the building, or in the basement of the building. The sketches shown in Figures 2a and 2b provide a proposed layout for a blower system installed in the middle room on the upper floor of the Valve House. Locating the blowers on the upper floor of the building is possible but would provide minimal clearances around the blowers, reducing access. Therefore, for the purposes of this evaluation, it is assumed that the blowers will be installed in the basement of the Meridian Valve House building.

Installing the blowers in the basement on the Valve House would require that 42-inch holes be core drilled in the basement foundation wall to accommodate intake and discharge ducting for the blowers. This ducting would be constructed of HDPE or fiberglass and would be sealed at the foundation penetrations with link seals. The intake ducting would connect to a penthouse louver intake structure constructed adjacent to the building. Air would be drawn in through this structure and brought into an aluminum intake manifold located in the basement. The intake for each blower would be connected to this manifold. Each blower discharge would be connected to an aluminum discharge manifold located in the basement. HDPE discharge ductwork would extend from the blower discharge manifold through the basement foundation, underground to the manifold connecting the packed towers together. Figures 3a and 3b provide a proposed layout for blower system installed in the basement of the Valve House.

The primary advantage of this alternative is that the blowers are located inside. Locating the blowers inside reduces noise emission and keeps the blowers out of the weather. However, this alternative has a number of disadvantages. First, the existing valve house structure must be modified. Such modification could potentially affect the structural integrity of the valve house building, necessitating additional structural modifications.

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Secondly, this alternative would require that ductwork be routed underground, potentially resulting in conflict with existing utilities. Thirdly, primary access to the basement is through a 36-inch wide stairwell, making maintenance operations more difficult.

Alternative 3: Locate the Blowers in a New 432 Square Foot CMU Building

This alternative would locate the blowers in a new CMU building located immediately to the north of the packed towers. An aluminum intake manifold would be constructed along the eastern interior wall of the structure; intake louvers would be installed along the eastern wall of the building and would be connected to the intake manifold. An aluminum discharge manifold would collect air from the blowers and route it through the south wall of the building to the manifold connecting the packed towers together. Figure 4 provides a proposed site layout with a new CMU building to house the blowers.

This alternative has similar advantages to Alternative 2. However, since the new building would be constructed adjacent to the packed towers, underground ductwork would not be required, eliminating the potential for conflicts with existing utilities. Furthermore, since the blowers would be housed in a new structure, there are no concerns related to modification of an existing structure.

COST ESTIMATES

Estimated costs for each alternative are summarized in Table 2. Detailed estimates are attached. Estimated costs only include the costs for building construction or modification, and ductwork. Costs for electrical, control, and the ductwork connecting the towers are excluded from the cost estimates since these items are required for each of the three alternatives. Alternative 1 is the simplest and lowest cost alternative since it does not require construction of a new building or modifications to an existing building. Table 2 lists the additional cost to locate the blowers according to Alternative 2 and Alternative 3.

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TABLE 2

Cost Estimates

Alternative(1)	Estimated Additive Cost
Alternative 1 – Locate Blowers Outside(2)	$0
Alternative 2 – Locate Blowers in the Existing Meridian Valve House(3)	$93,000
Alternative 3 – Locate the Blowers in a New 432 Square Foot CMU Building.	$122,000

(1) No additive cost is assigned for Alternative 1 since the components required for Alternative 1 are also required for Alternatives 2 and 3.

(2) The costs listed for Alternative 2 and Alternative 3 reflect the cost increase relative to Alternative 1.

(3) The estimated cost for Alternative 2 does not include any structural modifications to accommodate the basement wall penetrations.

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MEMORANDUM

TO: Tim Richardson, P.E.
City of Olympia
FROM: Mike Johnson, P.E.
Joe Plahuta, P.E.
DATE: November 20, 2013
SUBJECT: McAllister Wellfield Corrosion Control Project
Packed Tower Aerator Design Evaluation
Design Memo
G&O PROJECT NO: 12225.07

BACKGROUND

The proposed McAllister Wellfield is located in northeast Thurston County, approximately 4,000 feet to the southeast of the existing McAllister Springs facility. The wellfield will provide approximately 80% of the City of Olympia's source capacity and will pump directly to the Meridian Reservoirs through a 36-inch transmission main. The Meridian Reservoir Site is located approximately 7,000 feet to the northwest and is 28.4 acres in size. Each reservoir has a capacity of 4 million gallons and an overflow elevation of 301 feet.

As part of the McAllister Wellfield Project, a new corrosion control facility will be constructed at the Meridian reservoir site. This facility will utilized packed tower aerators to raise the pH of the water by removing dissolved carbon dioxide from the water prior to entering the reservoirs. The facility will initially consist of three aeration towers for a treatment capacity of 15 MGD. At a later date, a fourth tower will be constructed to provide a total treatment capacity of 23 MGD.

The aeration towers will be located on the northeast portion of the parcel in an area sloping to the east at an average elevation of approximately 293 feet. Inlet piping to the towers will be run from the existing transmission main while outlet piping will be connected to the existing reservoir bypass piping. Figure 1 shows a proposed piping schematic.

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Since the overflow of the existing reservoirs is located at an elevation of 301 feet, the outlet water surface elevation of the corrosion control towers will need to be located at an elevation equal to 301 feet plus the headloss in the piping between the towers and the reservoir at 23 MGD. The headloss between the towers and the reservoir at 23 MGD is approximately 3.3 feet, therefore, the outlet water surface elevation of the aeration tower will need to be at an elevation of approximately 305 feet. Since the existing ground surface is at an elevation of approximately 293 feet, the base of the packed towers will need to be elevated approximately 12 feet. The

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purpose of this memo is to evaluate different approaches to raising the base of the packed towers to an elevation of 305 feet.

TOWER MATERIAL

Packed tower aerators are typically constructed from aluminum, stainless steel, or fiberglass reinforced plastic (FRP). Each of these materials has intrinsic advantages and disadvantages.

Aluminum

Aluminum is frequently used for the construction of packed tower aerators. Aluminum has good structural properties and is generally resistant to corrosion in a potable water environment. However, unlike stainless steel or FRP, aluminum is not inherently resistant to corrosion but instead relies upon a thin oxide layer to protect the base metal from corrosion. Like stainless steel, aluminum is somewhat malleable and is therefore resistant to fatigue cracking from thermal expansion and contraction. Aluminum is also immune to photodegradation. In terms of cost, aluminum is competitive with FRP, and considerably less expensive than stainless steel.

Stainless Steel

Stainless steel is a less commonly utilized material for packed tower aerators due to its high cost. However, due to its corrosion resistance and strength, it is more durable than either aluminum or FRP. Like aluminum, stainless steel is highly resistant to fatigue cracking and does not photo-degrade. However, stainless steel is also very expensive so its use is typically limited to applications handing hot and/or corrosive liquids.

Fiberglass Reinforced Plastic (FRP)

FRP consists of glass strands imbedded in a matrix of resin material (typically epoxy, or vinyl ester). FRP is a commonly used and economical material for packed tower aerators. This is particularly true in the northwest where the mild climate lessens concerns relating to thermal stress. In general, FRP is very durable and highly corrosion resistant; however, it can be subject to degradation from sunlight and fatigue cracking from thermal expansion and contraction. Furthermore, the resins in FRP tend to lose plasticity with time, making the material more brittle with age. Resin degradation can be mitigated by application of a protective coating to the exterior of the tower.

Since western Washington experiences relatively low thermal extremes, FRP is the preferred material due to its excellent corrosion resistance and relatively low capital costs.

TOWER CONSTRUCTION

Four different alternatives were evaluated for elevating the towers in order to allow treated water to flow from the towers to the reservoir.

1. Purchase the packed towers with an integral clearwell.

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2. Install the packed towers on a cast-in-place concrete clearwell.

3. Construct the packed towers on a concrete mechanical building.

4. Construct the towers are placed on a slab-on-grade, cast on fill material placed behind a retaining wall.

Each of these alternatives is discussed further below. Alternatives 1, 2, and 3 do not require significant modification of the grades at the reservoir site since the clearwell is used to provide the necessary elevation. Alternative 4 would require substantial earthwork and construction of a retaining wall in order to provide the necessary base elevation for the aeration towers. A cost summary for each of the alternatives is provided in Table 1.

Alternative 1 – Integral Clearwell

This alternative would provide a clearwell integrated into the base of the packed tower aerator to elevate the aeration towers. The existing ground surface elevation at the proposed location of the aeration towers would be filled to an elevation of approximately 295 feet. This necessitates that the clear well be approximately 11 feet high in order to provide a water surface elevation of 305 feet and 1 foot of freeboard. Therefore, the aeration tower furnished by the manufacturer would be approximately 36 feet tall. The entire aeration tower and sump assembly would be secured to a concrete slab with an elevation of 295 feet.

The advantage of this alternative is that the aeration tower and sump can be manufactured together, minimizing the amount of work needing to be performed onsite. However, assuming that the blowers are located at ground level, additional ducting would be required to reach the air inlet at the base of the aeration tower. The estimated cost for constructing this alternative is $2,480,000. Figure 2 shows a schematic depiction of Alternative 1.

Alternative 2 – Concrete Clearwell

This alternative would provide a cast-in-place concrete clearwell to elevate the base of the aeration towers. The existing ground surface elevation at the proposed location of the aeration towers is approximately 295 feet. This necessitates that the clear well be approximately 11 feet high in order to provide a water surface elevation of 305 feet, 1 foot of freeboard, and 1 foot of top slab thickness. Therefore, an 11 foot high concrete clearwell would be constructed with a top elevation of 307 feet. The aeration towers would be anchored to the top of the clearwell and the connection between the tower and the clearwell engineered to resist overturning. The total height of the aeration tower assembly supplied by the manufacturer would be approximately 25 feet.

The estimated cost for constructing this alternative is $2,603,000. Figure 3 shows a schematic depiction of Alternative 2.

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Alternative 3 – Concrete Mechanical Building

This alternative would provide a cast-in-place concrete mechanical building to elevate the base of the aeration towers. The existing ground surface elevation at the proposed location of the aeration towers is approximately 295 feet. This necessitates that the concrete building be approximately 10 feet high in order to provide a tower base elevation of 305 feet. Therefore, a 10 foot high concrete building would be constructed with a top elevation of 305 feet. The aeration tower would be anchored to the top of the building and the connection between the tower and the building engineered to resist overturning. The total height of the aeration tower assembly supplied by the manufacturer would be approximately 25 feet.

Piping would exit the base of each tower and feed into a common header located in the space within the concrete structure. The blowers would be located in the concrete structure for weather protection and to reduce noise. This alternative is similar to the concrete clearwell alternative. Waterstops would not be required, but heating, ventilation, and air conditioning (HVAC) provisions would need to be made and floor drains would need to be installed in the building. The estimated cost for constructing this alternative is $2,712,000. Figure 4 shows a schematic depiction of Alternative 3.

Alternative 4 – Grading Modifications

This alternative would provide the necessary tower base elevation thorough filling, grading, and construction of a retaining wall. The grade at the proposed location of the aeration towers would be raised approximately 10 feet to an elevation of 304 feet. Since the area where filling will take place is located on a slope, a retaining wall approximately 12-foot tall would need to be constructed along the east side of the aeration towers to provide a level foundation for the aeration towers. A concrete foundation slab would then be poured to a top-of-slab elevation of 305 feet. The aeration tower assembly would then be anchored to this slab and piping made up through the bottom of the slab to the base of the aeration tower.

The estimated cost for constructing this alternative is $2,608,000. Figure 5 shows a schematic depiction of Alternative 4.

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TABLE 1

Construction Costs Summary

Alternative	Description	Cost	
1	Integral Clearwell	$	2,480,000
2	Cast in-place Concrete Clearwell	$	2,603,000
3	Cast in-place Concrete Mechanical Room	$	2,712,000
4	Fill Pad with Retaining Wall	$	2,608,000

Alternative No. 1 is the preferred alternative since it has the lowest capital cost.

Gray & Osborne, Inc.
CONSULTING ENGINEERS

MICHAEL B. JOHNSON
38408
5/6/13

TECHNICAL MEMORANDUM 9

TO: TIM RICHARDSON, P.E.
CITY OF OLYMPIA
FROM: MIKE JOHNSON, P.E.
RUSS PORTER, P.E.
MYRON BASDEN, P.E., S.E.
DATE: MAY 6, 2013
SUBJECT: FEASIBILITY EVALUATION FOR MOUNTING PACKED TOWERS ON THE EXISTING MERIDIAN RESERVOIRS, MCALLISTER WELLFIELD
CITY OF OLYMPIA, THURSTON COUNTY, WASHINGTON
G&O #12225.04

INTRODUCTION

Gray & Osborne has prepared a Corrosion Control Optimization and Alternatives Analysis Report for the City of Olympia's McAllister Wellfield project. The preferred alternative identified in this report is the construction of a packed tower aeration facility at the Meridian Reservoir site. This memorandum evaluates the feasibility of locating the packed tower aeration facility on top of one of the Meridian Reservoirs.

The Meridian Reservoirs are partially buried 4.0 million gallon prestressed concrete reservoirs. Reservoir 1 was constructed in 2003 and Reservoir 2 was constructed in 1997. For this analysis, the following documents were reviewed:

- Meridian Reservoir No. 1 Replacement and Site Development Record Drawings (EES/CH2MHill, November 2004),
- Meridian Reservoir No. 2 Record Drawings (EES, 1999),
- Geotechnical Data Report – Meridian Reservoir No. 1 Replacement (CH2M Hill, May 2003),

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- Geotechnical Engineering Report – Meridian Heights Water Tank (AGRA, February 1997), and
- Meridian Reservoir No. 1 Replacement and Site Improvements – Structural Calculations and Design Data (CH2M Hill, April 2003).

Since design calculations were only provided for Reservoir 1, a detailed evaluation was only completed for Reservoir 1. Due to the similarities in the type of construction of the reservoirs, it is anticipated that the findings and conclusions would be similar for Reservoir 2.

ASSUMPTIONS

The packed towers are assumed to be 14 feet in diameter and 25 feet in height.

Each packed tower is assumed to have an operating weight of 100,000 pounds.

Soil-bearing capacity is assumed to be 4,000 pounds per square foot (psf) (based on the Geotechnical Reports).

EVALUATION

Roof Slab –Vertical Loads

According to record drawings for Reservoir 1, the roof slab consists of 8-inch thick concrete, with thickened portions at the columns (a.k.a. "drop panels") that have a total thickness of 12-1/4 inches. The roof slab spans approximately 22'-10" to regularly spaced concrete columns. According to the design calculations dated April 3, 2003, the reinforcing in the slab is designed only for self-weight of the concrete plus 10 psf additional dead load and 25 psf live/snow load. The proposed new packed towers, at 100,000 pounds and 14 feet in diameter, would have a bearing pressure at their footprint of approximately 650 psf. The existing roof slab would therefore be severely overstressed by placing the packed towers directly on the roof slab.

To place the new packed towers on the roof of Reservoir 1, the load would need to be distributed over a wider area. One way to do this would be to install new steel "I" beams on top of the roof slab which would span to the existing 24-inch diameter concrete columns of the reservoir. This would effectively prevent any additional weight from being applied to the existing roof slab. These new steel beams would need to be sized to limit deflection to prevent cracking of the existing concrete roof slab. Based on the weight of the packed towers and the 22'-10" span between columns, the new steel beams

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would need to be at least 21 inches deep and have a self-weight of at least 60 plf. Overturning resistance would need to be provided at the interface between the new steel framing and the existing concrete roof. This could be achieved with either post-installed anchor bolts located at the existing 24-inch concrete columns or by extending the steel framing beyond the packed towers as required to prevent overturning (i.e., create a "roof sled"). All the new structural steel would need to be coated and maintained during its service life.

Roof Slab – Earthquake Loads

The connection of the existing roof slab to the perimeter wall consists of a 5-inch square steel tube projecting from the perimeter wall into the underside of slab, detailed to allow for thermal expansion and contraction of the concrete roof slab. The original calculations show that the connection has been designed to resist horizontal earthquake loads from the roof of the reservoir. The addition of the packed towers on the roof would increase the horizontal earthquake loads at these connections. Based on the calculations dated April 3, 2003, the connection has about 15 percent of reserve capacity. Depending on the exact layout of the towers, the towers could add up to 35 percent more earthquake load at these connections. Furthermore, any modifications would have to be designed to the current building code, which likely requires slightly higher earthquake loads than the previous version of the building code that the reservoir was designed for. To add more capacity for horizontal loads, the connection would need to be demolished and rebuilt. This work would likely require the reservoir to be taken out of service and would be costly.

Concrete Columns

According to the record drawings, the concrete support columns in the reservoir are 24 inches in diameter with 16 #8 vertical bars equally spaced around the perimeter and regularly spaced horizontal ties. According to the original design calculations, the existing concrete columns appear to have adequate reserve capacity to support the added weight of new packed towers on the roof.

Concrete Footings

According to the record drawings for the reservoir, a footing is located under each concrete column, and the footing is 5'-0" square by 2'-0" deep. From the edges of the footings, the thickness tapers down from 2"-0" to the 6-inch thickness of the typical slab on grade. The allowable soil-bearing pressure recommended by the original Geotechnical Report is 4,000 psf. According to the original calculations, the footings are

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sized only for the load from the column and the weight of water in the reservoir, resulting in a bearing pressure demand of nearly 4,000 psf, without any additional reserve capacity.

If packed towers were added to the roof of the reservoir, the bearing pressure of the existing footings would be increased by at least 1,000 psf to 5,000 psf. This exceeds the allowable pressure of 4,000 psf and could cause settlement and cracking of floor or roof slabs. To provide additional bearing capacity, the bearing area of the footings would need to be increased. This would require taking the reservoir out of service in order to demolish and reconstruct the footings and the floor of the reservoir in the area around the existing footings. The construction of these modifications would be disruptive and costly. Resealing the floor of the reservoir to prevent leakage might also prove challenging.

Attachments and Miscellaneous Modifications

Adding the packed towers onto the roof of the reservoir would require other miscellaneous additions/revisions to the existing reservoir. These include adding a stairway or ladder to the exterior wall of the reservoir to access the roof, providing pipe supports on the existing reservoir for piping from the packed towers, and installing pipe penetrations into the existing reservoir. Such attachments are not possible at the wall of the reservoir due to the horizontal prestress wires that wrap around the walls of the reservoir. These attachments would need to be made to the reinforced concrete roof or would need to be supported from the ground.

FINDINGS AND RECOMMENDATION

Based on analysis described above, our findings are as follows:

- The existing roof slab does not have enough reserve capacity to support the additional vertical loads of the packed towers. This could be addressed by adding steel beams above the roof slab which span to the existing concrete columns.
- The connection of the existing roof slab to the perimeter wall may not have enough reserve capacity for the added horizontal earthquake loads from the packed towers. To add more capacity for horizontal loads, the connection would need to be demolished and rebuilt.
- The existing concrete columns are adequate to support the additional loads.

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- The existing footings do not have adequate bearing area to support the additional loads. Modifying the footings would require taking the reservoir out of service and replacing sections of the reservoir floor to increase the bearing area of the footings.

- Placing the towers on the existing roof may require a number of attachments and supports. Attachment to the reservoir walls will not be possible due to the horizontal prestress wire that wraps around the walls of the reservoir. Attachments would need to be made to the concrete roof or supported from the ground.

In consideration of the findings above, Gray & Osborne recommends against placing the packed towers on the roofs of the Meridian Reservoirs.

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APPENDIX D

PROJECT CONSTRUCTION COST

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City of Olympia
McAllister Wellfield - Corrosion Control Facility
Construction Cost Estimate

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BASE BID:

NO	DESCRIPTION	QUANTITY	UNIT PRICE	AMOUNT
1	Minor Changes	1 CALC	$ 20,000	$ 20,000
2	Record Drawings	1 LS	$ 1,000	$ 1,000
3	Mobilization and Demobilization	1 LS	$ 248,000	$ 248,000
4	Unsuitable Excavation	40 CY	$ 35	$ 1,400
5	Gravel Borrow	2300 TN	$ 15	$ 34,500
6	Controlled Density Fill	10 CY	$ 150	$ 1,500
7	Trench Safety System	1 LS	$ 30,000	$ 30,000
8	Crushed Surfacing Top Course	360 TN	$ 25	$ 9,000
9	Crushed Surfacing Base Course	700 TN	$ 25	$ 17,500
10	Commercial HMA	430 TN	$ 120	$ 51,600
11	Erosion Control	1 LS	$ 5,000	$ 5,000
12	Topsoil	100 CY	$ 35	$ 3,500
13	Restoration	1 LS	$ 5,000	$ 5,000
14	Sitework	1 LS	$ 60,000	$ 60,000
15	Foundation Gravel	170 CY	$ 40	$ 6,800
16	CMU Blower Building	1 LS	$ 150,000	$ 150,000
17	Reinforced Concrete Slab	1 LS	$ 60,000	$ 60,000
18	FRP Aeration Towers	1 LS	$ 1,319,500	$ 1,319,500
19	Centrifugal Blowers and Ductwork System	1 LS	$ 65,000	$ 65,000
20	Piping, Valves, and Appurtenances	1 LS	$ 710,000	$ 710,000
21	Electrical, Telemetry, and Instrumentation	1 LS	$ 292,000	$ 292,000
	Subtotal			$ 3,091,300
	Washington State Sales Tax (7.9%)			$ 244,213
	Subtotal			$ 3,335,513
	Contingency (5%)			$ 166,776
	Total Estimated Construction Cost (Base Bid)			**$ 3,502,300**

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Auburn Water System

Corrosion Control Study
Final Draft Report

June 1995

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ECONOMIC AND ENGINEERING SERVICES, INC.

ENERGY • RESOURCE • MANAGEMENT • CONSULTANTS

Auburn Water System

Corrosion Control Study
Final Draft Report

June 1995

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Prepared by:

Economic and Engineering Services, Inc.
P.O. Box 1989
Bellevue, Washington 98009
(206) 451-8015

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CERTIFICATION

This Lead and Copper Rule Corrosion Control Study Report for the City of Auburn, June 1995, has been prepared under the direction of the following Registered Professional Engineer.

Gregory J Kirmeyer

Gregory J. Kirmeyer, P.E.

GREGORY J. KIRMEYER
STATE OF WASHINGTON
001648
REGISTERED
PROFESSIONAL ENGINEER

EXPIRES 09/07/95

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CHARLES A. BOOTH, MAYOR
Frank A. Currie, Director of Public Works
Dennis R. Dowdy, City Engineer

ENGINEERING DIVISION
25 West Main, Auburn WA 98001-4998
(206) 931-3010

June 19, 1995

ROBERT E JAMES PE
REGIONAL ENGINEER
DEPARTMENT OF HEALTH
NW DRINKING WATER OPERATIONS
1511 THIRD AVENUE SUITE 719
SEATTLE WA 98101 1632

RE Corrosion Control Requirements
Lead and Copper Rule

Dear Mr. James:

The City of Auburn has prepared this Corrosion Control Study in compliance with the Lead and Copper Rule Requirements of EPA and DOH, as we understand them. The City is committed to providing a safe and reliable water supply to all of our customers, a commitment which is fully supported by our Mayor and Council. We feel compelled however, to comment on the Lead and Copper program and the interpretation of the rules as taken by the DOH.

Although the City remains committed to developing a program to meet the intent of the Lead and Copper Rule, the City firmly believes the Lead and Copper Rule is flawed. The following is the basis for our opinion:

- Requiring the City to monitor and be responsible for water quality at locations beyond the meter, over which we have no authority, is unreasonable. While we may have some authority over our inside-the-City customers at the time of construction, we do not have the same authority outside the City, nor do we have any control of what happens to these private systems, including private site plumbing, inside foundation plumbing, and faucet locations such as in the kitchen or bathrooms once the plumbing inspection is completed.

- Requiring the City to implement treatment facilities to address conditions beyond our system is unreasonable, and again beyond our authority. We are convinced a significant majority of the action level exceedance could be investigated, and solutions applied locally, much more economically and efficiently to address the specific problem, rather than to implement a system-wide treatment alternative. It is not reasonable to burden the majority of ratepayers with an exorbitant system cost when a

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small expenditure applied directly to the specific private (non-system) site location will better accomplish the regulation goals.

- The City strongly disagrees with the DOH interpretation of the Lead and Copper Rule wording "optimize" to mean system treatment at all source locations. The City interprets "optimize" to mean; 1. To improve as far as possible, or, 2. To make the most effective use of' {which comes from the word "optimum" and means 'the best condition' }. These definitions come from "Webster's II". We believe this is intended to implement treatment as needed to remove our customers from the action level of contamination, not a triggering milestone calling for any and all possible expenditure regardless of benefit. This is particularly important to the City since we have just completed preparation of a Comprehensive Water Plan which has identified substantial water system improvements which will be required over the next several years. We must balance our treatment improvements with other system needs and implement individual improvements on a prioritized basis.

- The EPA has set a Maximum Contamination Level Goal (MCLG) for Lead at zero and has set an MCLG for copper at 1.3 mg/L. (It should be noted that Copper has some beneficial nutrient benefit to humans at low levels.) Implementing treatment to further lower Copper levels below the 1.3 mg/L level does not make economic sense or appear to be warranted on any health basis.

The City has, is, and will continue to meet regulatory requirements. We believe, in general, this to be in the best interest of our customers. The City must urge the DOH to be prudent and reasonable in application of regulations, to include a cost / benefit consideration, and include a willingness to effect an optimization of the ends, not just the means.

Sincerely,

Dwight L. Holobaugh, P.E.
Utilities Engineer
Department of Public Works

DLH/bd

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Executive Summary

Background

The City of Auburn, Washington conducted a corrosion control study to fulfill the requirements of the Lead and Copper Rule, which is administered by the U.S. Environmental Protection Agency and the Washington State Department of Health. The intent of the Lead and Copper Rule (LCR) is to reduce the concentrations of lead and copper in drinking water. Lead is a highly toxic metal with no known benefits to human health. USEPA has established a non-enforceable health goal, known as a Maximum Contaminant Level Goal (MCLG)[*], of zero for lead in drinking water. USEPA has established an MCLG of 1.3 mg/L for copper, which is a beneficial nutrient at low levels. Human exposures above 1.3 mg/L may cause gastrointestinal distress and people with Wilson's disease must avoid copper in their diets. USEPA also has established enforceable regulations that mandate corrosion treatments based on tap water monitoring results.

Nationwide, the presence of lead and copper in drinking water is a result primarily of corrosion of materials in water distribution systems and home plumbing which contain these metals. The concentration of lead and copper in water is determined by corrosion factors such as the amount and age of lead and copper bearing materials in contact with water, the length of time water is in contact with these materials, and water quality characteristics. Lead concentrations in Auburn water generally are low compared to the lead action level of 0.015 mg/L. Small amounts of lead originate from lead:tin solder that was historically used to join copper pipe and from brass faucets and fixtures which contain lead. Copper concentrations in Auburn's water barely exceed the USEPA action level of 1.3 mg/L. The main sources of copper in the drinking water are from corrosion of copper piping in service lines and premise piping, and brass fixtures, which are present in the Auburn service area.

The LCR requires water systems to complete water quality monitoring programs for lead and copper at customers' taps, provide public education programs as warranted by the results of water quality monitoring, and provide corrosion control treatment for reducing lead and copper levels in drinking water. The schedule and requirements of the LCR vary depending on the size of the water system and results of monitoring. The LCR monitoring program requires first-flush water samples

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[*] *MCLGs are non-enforceable health goals which are based solely upon consideration of protecting the public from adverse health effects of drinking water. MCLGs do not impose any obligation on public water systems. MCLs are enforceable standards set as close to the MCLG as is feasible. Action levels are defined in the Lead and Copper Rule as the concentration of lead or copper in water that determines whether a water system must install corrosion control treatment or undertake some other action. The status of a system relative to the action levels of the Lead and Copper Rule is determined by calculating the 90th percentile concentrations of samples collected at-the-tap in the system.*

collected from customers' taps after the water has been standing for a minimum of six hours. By exceeding the action level of 0.015 mg/L for lead or 1.3 mg/L for copper in more than 10 percent of samples collected during this monitoring program, then medium sized systems such as Auburn are required to conduct a corrosion control study for lead and copper corrosion. Auburn exceeded the action level for copper and accordingly has prepared this report.

Auburn must submit the results of the corrosion control study and recommend a corrosion control treatment plan to the Washington State Department of Health (DOH) by July 1, 1995. DOH must review the report and designate a corrosion control treatment for Auburn by January 1, 1996. Under the LCR, the State may designate the treatment recommended by Auburn or it may choose to designate a different treatment. Corrosion treatment facilities must be on-line by January 1, 1998 to meet the requirements of the LCR. It should be emphasized that although Auburn exceeded the copper action level, Auburn remains in full compliance with the requirements of the LCR since appropriate steps have been taken to study the issue and install treatment.

Water System

The Auburn water system supplies drinking water to approximately 40,000 people in a service area encompassing approximately 25 square miles in south King County, Washington. The Auburn water supply is obtained from two springs and seven wells. The average daily demand is approximately 7 million gallons and the historical peak day demand is 15 million gallons. The Coal Creek springs and West Hill springs are disinfected with gaseous chlorine, and free chlorine residual typically ranges from 0.1 to 0.8 mg/L in the distribution system.

Auburn's water transmission and distribution system includes approximately 195 miles of pipe, which consists of 58 percent ductile iron, 39 percent lined cast iron, 2 percent unlined asbestos cement, and the remaining 1 percent consisting of unlined steel and concrete pressure pipe. Customer service lines in the Auburn system are made up of approximately 20 percent copper, 35 percent galvanized steel, and 45 percent polyethylene or polybutylene material.

Water Quality

According to the requirements of the Lead and Copper Rule, the 90th percentile action levels are 0.015 mg/L for lead and 1.3 mg/L for copper. Water quality data collected during initial monitoring for the Lead and Copper Rule indicate that Auburn did not exceed the 90th percentile action level for lead, but Auburn did barely exceed the 90th percentile action level for copper. The 90th percentile levels for the Auburn system were 0.006 mg/L for lead and 1.57 mg/L for copper for the first round of monitoring in 1992, and 0.006 mg/L for lead and 1.5 mg/L for copper

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for the second round of monitoring in 1993. Auburn therefore needs to control copper corrosion in the system to meet the requirements of the Lead and Copper Rule.

Source water quality samples were collected from the Coal Creek springs and six of Auburn's wells during initial monitoring for the Lead and Copper Rule. Samples were not collected from West Hill springs and Well #5A because the West Hill springs was not operational during initial monitoring and Well #5A typically is used as a back up for Well #5. Water quality data for the Auburn sources are summarized on Table ES-1.

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Table ES-1
Auburn Water System
Average Source Water Quality Parameters*

Parameter	Well #1	Well #2	Well #3A	Well #3B	Well #4	Well # 5[a]	Coal Creek Springs	Hidden Valley[b]
DOH Source ID #	S03	S04	S05	S08	S06	S07	S01	S01
pH	6.39	6.44	6.59	6.72	6.30	6.81	6.49	6.54
Temperature (°C)	11.5	11.7	11.25	11.1	10.8	9.7	10.6	9.9
Alkalinity (mg/L as $CaCO_3$)	64	95	94	96	58	71	46	66
Calcium (mg/L as $CaCO_3$)	59	63	42	48	44	38	30	42
Conductivity (µmho/cm)	178	226	183	190	144	150	112	136
Calculated Free CO_2 (mg/L)[c]	55	85	50	50	60	28	34	48
Lead (mg/L)	<0.002	<0.002	<0.002–0.005	<0.002	<0.002	0.002	<0.002	<0.004
Copper (mg/L)	<0.02–0.06	0.02–0.15	<0.02–0.05	<0.02–0.15	<0.02	<0.02	<0.02	<0.02
Iron (mg/L)[d]	<0.03–0.08	<0.03–0.24	0.24–1.22	<0.03–0.16	<0.03–0.46	<0.03–0.12	<0.03-0.04	0.05
Manganese (mg/L)[d]	<0.01–0.015	<0.01	0.112–0.179	0.360–0.463	<0.01	<0.01	<0.01	<0.01
Radon-222 (pCi/L)[e]	215	270	205	225	240	710	285	–

* *Average based on samples collected at the point of entry for each source during monitoring for the Lead and Copper Rule in 1992 and 1993 (Appendix A). During initial monitoring for the Lead and Copper Rule, chlorination facilities were being moved and monitoring was not conducted at West Hill springs.*

[a] *Well #5A typically is used as a backup for Well #5.*

[b] *Water from the Hidden Valley source does not enter the Auburn distribution network.*

[c] *Based on nomograph in Standard Methods (1992).*

[d] *Based on samples collected from 1987 to 1994.*

[e] *Based on samples collected in August 1994.*

Based on data included on Table ES-1, water from Auburn sources exhibit low pH values (less than pH 7.5) and low to moderate alkalinity (50 to 150 mg/L as $CaCO_3$). The low pH of Auburn's sources likely is the primary factor contributing to the corrosivity of the water supply to copper piping in the Auburn system.

Findings of Study

The findings of this study regarding corrosion control priorities, major constraints, the performance of various treatments, and the recommended corrosion control treatment for the Auburn system are summarized below.

Corrosion Control Priorities

Water quality monitoring results indicate that source water levels of lead and copper are near or less than detection levels and are not a concern for the Auburn system. The distribution system and tap monitoring results verify that the water quality concern from a compliance standpoint are associated with the uptake of copper from copper piping and brass fixtures by corrosion. The cause of this water quality concern is attributed primarily to the low pH level in the Auburn water supply. Free chlorine associated with disinfection also increases corrosion of copper piping. Materials susceptible to corrosion and the priority of concern for the Auburn system are summarized on Table ES-2.

Major Constraints

Auburn's selection of corrosion control treatment is affected by regulatory and functional constraints. The corrosion control program which is selected by Auburn should not compromise the ability of Auburn to comply with other drinking water regulations including the Surface Water Treatment Rule, Total Coliform Rule, and the proposed Radon Rule.

The pending determination by the Washington State Department of Health regarding the classification of water sources as "groundwater under the direct influence" of surface water per the Surface Water Treatment Rule is identified as a major regulatory constraint for the Auburn system. Such a determination would affect Auburn's disinfection approach and could require upgrading of treatment facilities for certain sources. Compliance with the Total Coliform Rule also could be affected if a significant pH change is implemented for corrosion control. A higher level of monitoring and increase in disinfectant dosage may be required to maintain Auburn's superior level of bacterial control in the system.

In addition to primary and secondary disinfection requirements, the USEPA has proposed an MCL for radon of 300 pCi/L, but recent developments indicate that the final MCL may be established within the range of 200 to 1,000 pCi/L. Samples collected from Auburn sources which serve the Valley, Lea Hill, and Academy pressure zones exhibited radon concentrations ranging from 205 to 285 pCi/L and samples collected from sources which

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serve the Lakeland Hills pressure zone exhibited radon concentrations ranging from 710 to 825 pCi/L. Initial at-the-tap monitoring results collected from the Lakeland Hills area indicate lead concentrations ranging from <0.002 to 0.003 mg/L and copper ranging from 0.21 to 0.57 mg/L. Although corrosion treatment is not considered necessary for the isolated Lakeland Hills area, aeration treatment could be used in the future, if necessary, to remove radon in conjunction with corrosion control.

Table ES-2
Auburn Water System
Materials Susceptible to Corrosion in the Service Area

Materials	Location/ Appurtenances	Type of Concern	Priority of Concern—Basis
Copper Pipe	Location: Home Plumbing and Service Lines	Health: Copper Release Aesthetics: Blue Green Stains	High—LCR
Brass and Lead Solder	Location: Home Plumbing, Fixtures	Health: Lead and Copper Release Aesthetics: Blue Green Stains	Medium—LCR
Unlined Iron and Steel	Location: Distribution System	Aesthetic: Red/ Rusty Water Economic: Loss of Hydraulic Capacity, Pipe Failures	Medium—10 percent of pipe network
Galvanized Pipe	Location: Home Plumbing and Service Lines, Small Distribution Piping	Health: Zinc Aesthetic: Red/ Rusty Water Economic: Loss of Hydraulic Capacity, Pipe Failures	Low—Customer Impacts
Asbestos Cement	Location: Distribution System	Health: Asbestos Fiber Release Economic: Dissolution of Pipe	Low—0.5 percent of pipe network

Regarding functional constraints, Auburn currently is planning to construct a new pump station for the Lea Hill pressure zone and develop new ground water sources (Wells 6 and 7). The new pump station may provide a location for corrosion control treatment. The new wells are not expected to affect Auburn's selection of the type of corrosion control treatment, but they may impact Auburn's overall corrosion control strategy. Furthermore, if Auburn selects a phosphate-based inhibitor for corrosion control treatment, then

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DOH would require Auburn to install disinfection treatment for all sources and Auburn would need to add phosphates for all sources to maintain a uniform phosphate concentration in the distribution system. If Auburn selects pH adjustment for corrosion control treatment, then the use of sodium-based chemicals (e.g., caustic soda) may result in unacceptable levels of sodium (greater than 20 mg/L) for certain customers. Sodium would not be a concern for other treatment alternatives that are used to increase pH (e.g., addition of potassium hydroxide or aeration treatment), but these alternatives may pose other functional constraints such as increased capital and/or operational costs.

Performance of Various Treatments

pH/alkalinity adjustment, calcium precipitation, and corrosion inhibitors are identified in the Lead and Copper Rule as suitable corrosion control treatment alternatives for water systems that exceed either action level of the Rule. The applicability of each of these three corrosion control treatments was evaluated for the Auburn system. Calcium precipitation is not considered a viable treatment for the Auburn system due to low-moderate pH and alkalinity levels. Alkalinity adjustment also was eliminated as a viable treatment alternative for Auburn because the existing alkalinity of Auburn water falls within the optimal range for copper corrosion control and any significant change in alkalinity likely would not decrease the existing rate of copper corrosion. As a result of this evaluation, pH adjustment and corrosion inhibitors were identified as viable treatment alternatives for the Auburn system.

pH adjustment was compared to corrosion inhibitors for treatment in the Auburn system based on performance, regulatory and function constraints, reliability and operability, and costs. The performance of pH adjustment and phosphate-based inhibitor addition have been shown nationally and in the Pacific Northwest to be effective treatments for copper corrosion control. pH adjustment is compatible with Auburn's existing operations and future plans for water quality improvement (e.g., low-level VOC or radon removal by aeration, if necessary). The addition of a phosphate-based inhibitor would require treatment at every source to maintain uniform phosphate concentration, and the costs are estimated to be greater than pH adjustment alone. Although an increase in pH could reduce primary and secondary disinfection efficiency, the impact can be mitigated during operation of corrosion control treatment facilities and it does not warrant elimination of this treatment alternative.

Conclusion

The recommended corrosion control treatment for the Auburn system is pH adjustment to a system-wide pH of 7.0, and possibly up to pH 7.5 if needed.

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This recommendation is based on analogous system information, constraints, and theory as summarized below.

- ☐ pH adjustment has been used or is recommended for corrosion control treatment for other utilities in the Pacific Northwest including the Covington Water District, the City of Seattle, the City of Vancouver, Washington and the City of Portland, Oregon.

- ☐ pH adjustment is compatible with Auburn's current system operations and future plans for water quality improvement. If necessary, Auburn could construct aeration treatment for corrosion control and simultaneously remove VOCs or radon.

- ☐ Water quality data for Coal Creek springs, Well 1, Well 2, and Well 4 indicate pH values in the range of 6.3–6.5 for source waters. Based on theory, a pH increase to 7.0 is expected to reduce copper solubility by approximately 40 to 90 percent. To reduce Auburn's 90th percentile copper level from 1.57 mg/L to a level less than the action level of 1.3 mg/L, Auburn needs to treat the system to reduce the 90th percentile by 17 percent. Theoretical calculations indicate that the 90th percentile copper level can be reduced below the action level of 1.3 mg/L by increasing the pH in the Auburn system to approximately 7.0. Unlike lead, copper solubility theory provides a better basis for predicting copper concentrations at-the-tap.

- ☐ At-the-tap monitoring conducted by Seattle (Chapman et al., 1989) indicate a 50 percent reduction in copper for samples collected before and after a pH increase from 7.2 to 8.2. Based on theory, copper solubility is calculated to be reduced by approximately 96 percent by increasing the pH in Seattle water from 7.2 to 8.2. Theoretical estimates of the reduction in copper solubility are approximately two times greater that at-the-tap monitoring results. Based on this comparison, a pH increase in Auburn water from 6.3-6.5 to 7.0 is expected to reduce the at-the-tap 90th percentile copper concentration by approximately 20 to 45 percent (rather than 40 to 90 percent based on theory alone). Furthermore, a pH increase to 7.0 is expected to reduce Auburn's 90th percentile copper concentration below the action level of 1.3 mg/L.

Auburn can reduce the 90th percentile copper concentration below the action level of 1.3 mg/L by implementing a staged approach to copper corrosion control. The first stage of the treatment strategy is to attain a system-wide blended pH of 7.0 and monitor the effects of treatment in the distribution system. Auburn is expected to be able to achieve a system-wide blended pH

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goal of 7.0 based on hydraulic modeling and blending analysis as summarized below:

☐ Hydraulic modeling was conducted by Auburn to evaluate the zone of influence of each of Auburn's sources in the distribution system. Modeling results and historical production data indicate that water from Coal Creek springs covers the southern portion of the Auburn service area and represents approximately 54 percent of the total flow. The area served by Coal Creek springs was verified by residual chlorine concentrations measured in the distribution system. Water from Well 2 covers the northern portion of the Auburn service area and represents approximately 22 percent of total flow. These results indicate that treatment applied to Coal Creek springs and Well 2 would be expected to affect corrosion control in the vast majority of the Auburn system.

☐ A water quality blending analysis was conducted to evaluate the impact of corrosion control treatment for selected sources on the Auburn system. Flow-weighted pH values were estimated for the Auburn system by spreadsheet calculations and the results were verified by theoretical calculations. The results indicate that when approximately 76 percent of Auburn sources are treated at the source to pH 7.5, the system-wide blended pH can be elevated to approximately 7.0. This system-wide blended pH can be attained by treating the Coal Creek springs and Well 2 to a pH of 7.5 at the source. This treatment strategy is expected to result in at-the-tap copper concentrations below the action level of 1.3 mg/L.

Recommendations and Implementation

The recommended corrosion control treatment strategy for the Auburn system is summarized in Table ES-3 and described below. The strategy is to treat Coal Creek springs and Well 2 to increase the system-wide blended pH of Auburn water (exclusive of Lakeland Hills service area) to pH 7.0, and up to pH 7.5 if needed. Under existing conditions, the pH ranges from 6.4 to 6.6 in the distribution system. When water from Coal Creek springs and Well 2 is increased to pH 7.5 at the source, the flow-weighted pH for the Auburn system is estimated to be approximately 7.0.

The information on Table ES-3 shows the percentage of total flow for each source under existing conditions (based on 1994 production logs) and forecast flow for the year 2010. The recommended corrosion control treatment strategy does not include treatment for Wells 3A and 3B or Wells 5 and 5A. Wells 3A and 3B provide supplemental water during extreme peak flow periods and therefore are excluded from the treatment plan. Wells 5 and 5A serve only the Lakeland Hills service area and the water never mixes with the rest of the Auburn system. Water quality data collected during initial monitoring for the LCR indicate at-the-tap lead and copper levels below the action levels for samples collected in the Lakeland Hills service area. Additional at-the-tap monitoring will be conducted by Auburn in the Lakeland Hills area to verify the statistical significance of initial monitoring results.

Table ES-3
Auburn Water System
Recommended Source Water Treatment and Rational

Source	DOH Source ID #	Percentage of System Flow 1994	Percentage of System Flow 2010	Is Corrosion Control Treatment Recommended?	Rational
Coal Creek Springs	S01	54	28	yes	Water from Coal Creek springs serves the southern portion of the Auburn service area. Increase the pH at the source from 6.5 to 7.5.
West Hill Springs	S02	9	5	no	Water from West Hill springs is blended into the northwest service area and typically represents less than 10 percent of the total flow. Corrosion control treatment is not considered necessary for this source.
Well 1	S03	14	7	Possibly in Future	Water from Well 1 is pumped into the central portion of the Auburn service area. If necessary, corrosion control treatment may be installed for this well after the year 2000.
Well 2	S04	22	23	yes	Water from Well 2 serves the northern portion of the Auburn service area. Increase the pH at the source from 6.4 to 7.5.
Wells 3A and 3B	S04/S05	0	0	no	Water from Wells 3A and 3B exhibits naturally high levels of iron and manganese. Wells are used as supplemental supplies, on an emergency basis only. No corrosion control treatment is planned for these wells.
Well 4	S06	0	22	no	Water from Well 4 is blended with water from Coal Creek springs in a tank at the Coal Creek springs pump station. Dedicated corrosion control treatment facilities for this well are not considered necessary.
Wells 5 and 5A	S07/S09	1	1	no	Wells are used to serve the Lakeland Hills area exclusively. Initial monitoring results suggest that the 90th percentile lead and copper levels for the Lakeland Hills service area were below the action levels of the LCR. Corrosion control treatment is not considered necessary for the Lakeland Hills area. Additional at-the-tap monitoring will be conducted to confirm initial monitoring results.
Future Sources (Wells 6 and 7)	-	0	14	To be Determined	Water from future wells is expected to be similar to existing sources and not likely to impact Auburn's selection of a type of corrosion control treatment. If necessary, corrosion control treatment may be installed after the year 2000.

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pH Adjustment Approach

Options for increasing pH include chemical feed (e.g., sodium hydroxide, potassium hydroxide) or aeration treatment. To determine the most practical and cost effective pH adjustment for Auburn, pH titrations using caustic soda (or potassium hydroxide) should be conducted on treated and raw water from Coal Creek springs and Well 2. Pilot studies also should be conducted for aeration treatment to evaluate the applicability of stripping carbon dioxide to increase water pH.

Site Evaluation

Auburn needs to provide corrosive control treatment for Coal Creek springs and Well 2. A study needs to be conducted to evaluate the feasibility of treating multiple sources at central locations such as the planned pump station for the Lea Hill pressure zone. The location of the treatment facilities should allow for possible future compliance with Ct requirements of the GWDR and SWTR, and possible future requirements of the Radon Rule.

Lakeland Hills Monitoring

Samples will be collected from a minimum of 20 sites in the Lakeland Hills area to establish statistically representative 90th percentile levels for lead and copper (based on small systems serving from 501 to 3,300 people per the LCR). The results of these analyses will be used to confirm that Wells 5 and 5A, which serve the Lakeland Hills area, do not need corrosion control treatment.

Monitoring Near Untreated Sources

Samples will be collected from a minimum of 5 sites (based on small water systems serving up to 100 people per the LCR) in the areas near Auburn sources which are not treated for corrosion control. Monitoring will be conducted for West Hill springs, Well 1 and Well 4. Wells 3A and 3B will not be monitored because they are supplemental sources used for emergency purposes only. Results will be used to evaluate the effectiveness of corrosion control treatment in areas near untreated sources.

Implementation Strategy

Exhibit ES-1 illustrates the recommended staged implementation strategy for corrosion control treatment in the Auburn system. The first step of the corrosion control strategy will involve a pH increase for water from Coal Creek springs and Well 2 to pH 7.5 to attain a system-wide blended pH of 7.0. After a period of equilibration, tap water samples will be collected from

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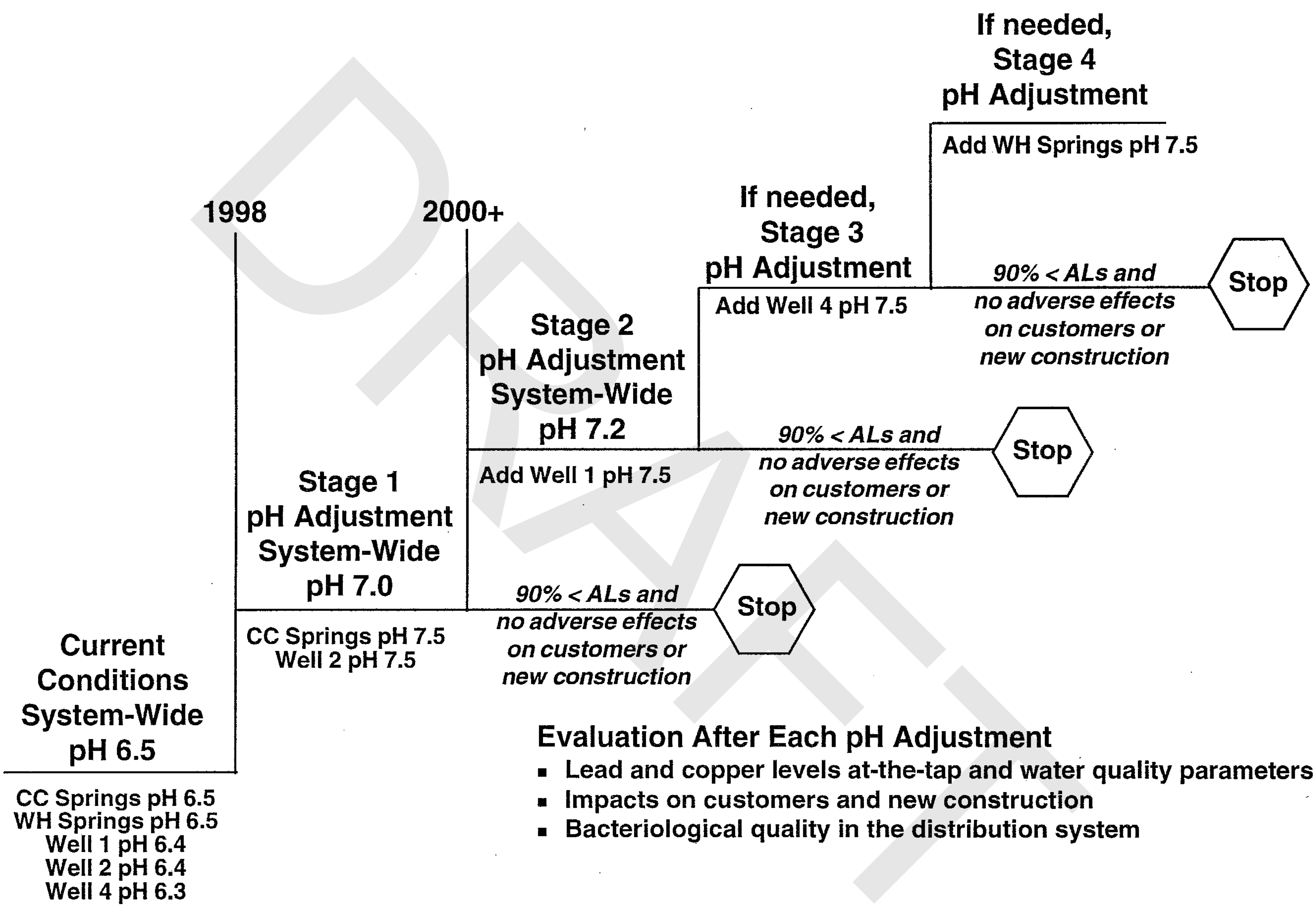

Evaluation After Each pH Adjustment

- Lead and copper levels at-the-tap and water quality parameters
- Impacts on customers and new construction
- Bacteriological quality in the distribution system

Exhibit ES-1
Auburn Water System
Recommended Implementation of Corrosion Control Strategy

the same sites sampled during baseline monitoring to assess the levels of lead and copper in the pH-adjusted water. If results are favorable, then treatment will continue at Coal Creek springs and Well 2 for three to six months, followed by additional tap water monitoring during the first six-month period of 1998. Treatment will be considered optimal when the following criteria are met:

☐ Copper levels are reduced and maintained below the action level of 1.3 mg/L at the 90th percentile;

☐ No significant adverse impacts of the treatment on bacteriological quality in the distribution system;

☐ No significant adverse impacts of the treatment on domestic customer satisfaction (e.g., red water due to disturbances in unlined cast iron, or black water attributed to precipitation of source water manganese);

☐ No significant adverse impact on commercial and industrial customers, health and facilities, and wastewater facilities; and

If follow up monitoring indicate that the 90th percentile action levels for copper are not met, then treatment will be modified to add treatment facilities at Well 1 (as part of Stage 2 of Auburn's corrosion control strategy). Additional monitoring will be conducted and results will be compared to the criteria listed above. Although not likely to be required, treatment could be modified further to construct treatment facilities for Well 4 and West Hill springs, if needed.

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Estimated Cost

For Auburn's Stage 1 corrosion control treatment strategy, the total capital cost to construct caustic soda feed facilities for Coal Creek springs and Well 2 is estimated to range from approximately $413,000 to $620,000. The total present worth (15 year return) to operate treatment at the two sources is estimated to be $5,264,000. If aeration technology is selected for pH adjustment in the Auburn system, then the capital cost to construct treatment facilities is estimated to be approximately $2,056,000 with a total present worth (15 year return) of $5,086,000.

For Auburn's Stage 1 and Stage 2 corrosion control treatment strategy, the total capital cost to construct caustic soda feed facilities for Coal Creek springs, Well 2, and Well 1 is estimated to range from approximately $578,000 to $867,000. The total present worth (15 year return) to operate treatment at the two sources is estimated to be $6,312,000. If aeration treatment is selected, then the total capital cost to construct treatment facilities is estimated to be approximately $2,548,000 with a total present worth (15 year return) of $6,661,000.

Next Steps

Exhibit ES-2 is a schedule for Auburn to comply with requirements of the Lead and Copper Rule. Because of the proposed extended implementation period, DOH and the City may need to negotiate an agreement which incorporates some of the items in this report. Upon finalizing the need for and terms of a bilateral compliance agreement and project approval by DOH, Auburn should begin engineering predesign, siting, design, and construction of treatment facilities for Coal Creek springs and Well 2 and complete construction for start-up by January 1, 1998. After start-up, Auburn will operate three to six months at a system-wide blended pH of 7.0. If monitoring results are favorable, then Auburn will continue operating at a system-wide blended pH of 7.0. If monitoring results are not favorable, then Auburn will evaluate alternative operations to reduce overall corrosion and the need to proceed with Stage 2, which may include construction of treatment facilities for Well 1.

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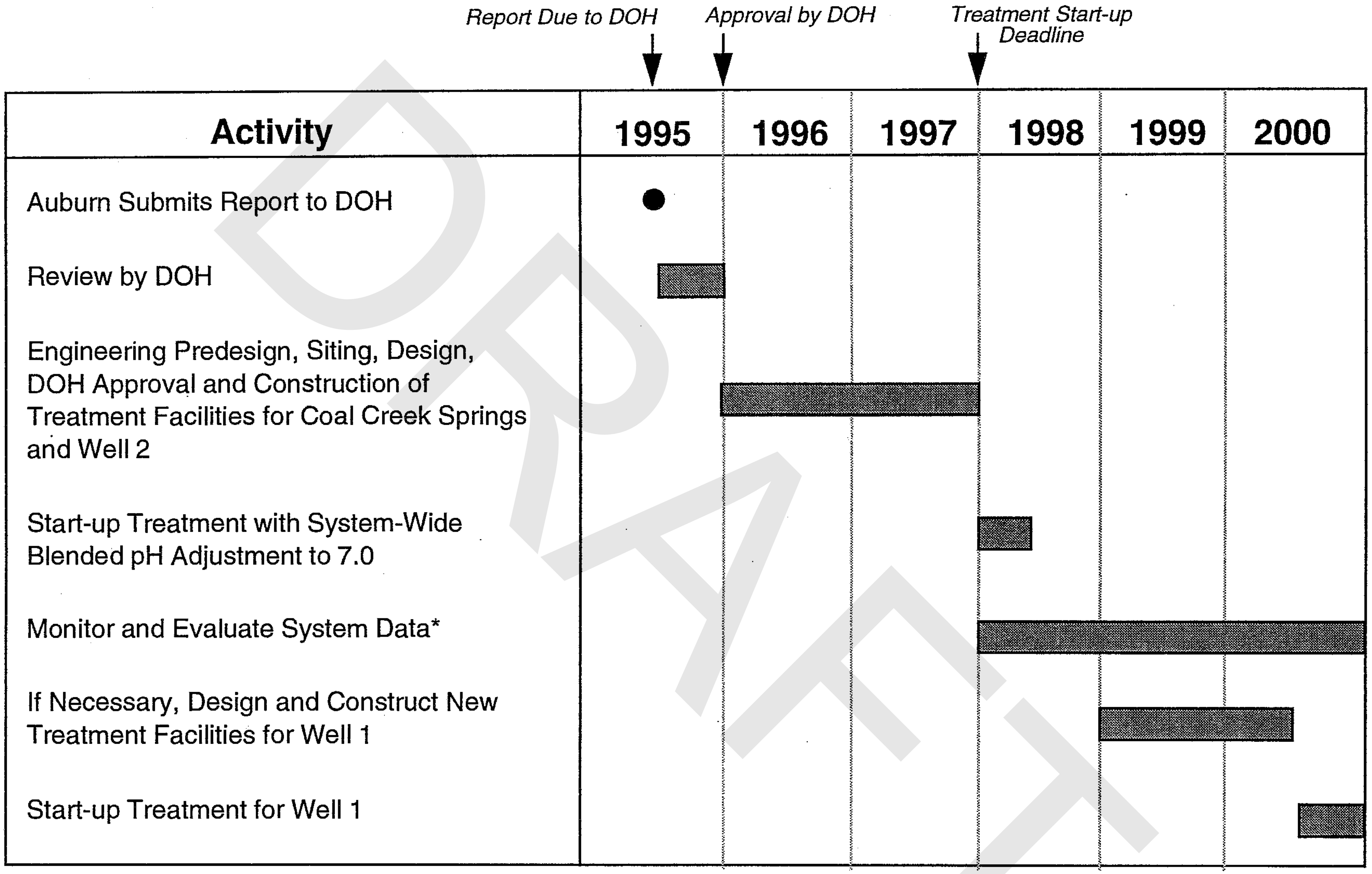

* *Monitoring results will determine need for additional corrosion control treatment. If Auburn remains below the action levels after installation of treatment, DOH may reduce monitoring frequency requirements.*

Exhibit ES-2
Auburn Water System
Lead and Copper Rule—Compliance Schedule

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Section 1
Introduction and Background

The City of Auburn (Auburn) is conducting a corrosion control optimization study in partial fulfillment of the federal Lead and Copper Rule (LCR). The LCR was promulgated by the United States Environmental Protection Agency (USEPA) to reduce lead and copper concentrations in drinking water. Ingestion of lead and/or copper via drinking water has been determined to pose certain health risks, especially for young children.

1.1 Requirements of the LCR

The LCR requires all medium-sized public water systems to complete water quality monitoring programs for lead and copper. If monitoring results indicate that a regulatory action level was exceeded, then the public water system must determine the "optimized" corrosion control treatment for reducing lead and copper in their drinking water supply. For medium size systems such as Auburn, optimal corrosion control treatment means the option most likely to assure that the lead and copper concentrations will remain below the action levels in subsequent monitoring periods without violating any other drinking water standard, also considering constraints particular to the system (DOH, 1994). The critical elements of the LCR include the following:

☐ At-the-tap monitoring;
☐ Desktop evaluation of treatment alternatives;
☐ Recommendation for treatment alternatives;
☐ Bench scale and/or pilot scale testing of alternatives (if required by State);
☐ Full-scale implementation of treatment; and
☐ Long-term monitoring.

Optimal corrosion control treatment should not adversely affect the overall water quality of the water system. USEPA defines "optimal corrosion control" as "the corrosion control treatment that minimizes lead and copper levels at users' taps, while ensuring that the treatment does not cause the water system to violate any national primary drinking water regulation." Therefore, for the State to approve a corrosion control strategy, it must be demonstrated that this strategy will not cause the water system to be out of compliance with other water quality regulations.

Under the LCR, the State will specify a range of values for water quality parameters under which a system must operate to control corrosion. Once the State specifies these ranges of values, they become enforceable requirements of the

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National Primary Drinking Water Regulations. A summary of the LCR compliance schedule for the Auburn system is included on Table 1-1.

Table 1-1
Lead and Copper Rule Compliance Schedule for Auburn Water System*

Date	Activity
July 1, 1995	Auburn must submit corrosion control treatment study report to State.
January 1, 1996	State approves/designates treatment.
January 1, 1998	Auburn must complete treatment installation.
July 11, 1998	Auburn must submit to the State the results of first six-month follow-up monitoring.
July 1, 1999	State specifies optimal water quality parameters.

* *Based on* Lead and Copper Rule Guidance Manual, Volume II: Corrosion Control Treatment, *1992.*

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Depending on the corrosion control treatment installed, the State designated corrosion control parameters that may be regulated could include one or more of the following:

- ☐ An optimum range of pH values measured at each entry point to the distribution system;
- ☐ If a corrosion inhibitor is used, a minimum or a range of inhibitor concentrations measured at each entry point to the distribution system and in all tap samples;
- ☐ If alkalinity is adjusted, a minimum or a range of alkalinity concentrations measured at each entry point to the distribution system and in all tap samples; and
- ☐ If calcium carbonate stabilization is used, a minimum or range of calcium concentrations measured in all tap samples.

1.2 Auburn Status and Study Approach

Auburn completed its initial six-month monitoring period in December 1992. The 90th percentile concentration for lead was 0.006 mg/L, which was 40 percent of the action level of 0.015 mg/L. The 90th percentile concentration for copper was 1.57 mg/L, which was 21 percent greater than the action level of 1.3 mg/L.

A second round of monitoring was completed by Auburn in June 1993. The 90th percentile concentration for lead was 0.006 mg/L and the 90th percentile concentration for copper was 1.5 mg/L. These results were similar to the initial six-month monitoring period, and confirmed the previous observation that the copper action level was exceeded by less than 21 percent (15 percent for this second round of monitoring). As a result, Auburn retained Economic and Engineering Services, Inc. (EES) to conduct the desktop evaluation and make recommendations to Auburn in developing treatment alternatives. The following steps were completed for the desktop evaluation consistent with Washington State Department of Health (DOH) guidance documents (DOH, 1994):

☐ Step 1—Define Existing Conditions
☐ Step 2—Evaluate Need for Source Lead or Copper Removal Treatment
☐ Step 3—Examine Corrosion Control Experiences
☐ Step 4—Define Constraints
☐ Step 5—Eliminate Unsuitable Approaches
☐ Step 6—Evaluate Viable Alternatives
☐ Step 7—Recommendation

The goal of the study is to recommend a preferred method or methods for Auburn's implementation of corrosion control treatment per the requirements of the Lead and Copper Rule.

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1.3 Project Background

The Auburn water system serves approximately 40,000 people and is classified as a medium size system for the purpose of the Lead and Copper Rule. As a medium size system, Auburn was required to conduct initial monitoring for lead and copper during the six-month monitoring period from July through December 1992. Initial monitoring consisted of determining lead and copper levels at targeted "high-risk" consumer taps. If an action level was exceeded, monitoring was required for various water quality parameters from the entry point to the distribution system and at representative locations within the distribution system. Water quality parameters include pH, alkalinity, calcium, conductivity, and temperature. If an action level was not exceeded, a second round of monitoring was required from January through July 1993.

Auburn's pool of targeted sampling sites consisted of 55 Tier 1 sites (single-family structures with copper pipes with lead solder installed after 1982 or lead pipes and/or lead service lines) and five Tier 3 sites (sites that contain copper pipes with lead solder installed before 1983). During the monitoring period, all sampling sites were understood by Auburn to be Tier 1, but subsequent information indicated that five of the homes were either built or re-plumbed before 1982. These five sampling sites are thus classified as Tier 3.

Results obtained by Auburn for lead and copper monitoring are plotted on Exhibits 1, 2, 3, and 4 and summarized on Table 1-2. Exhibits 1-1 and 1-2 show the results of lead and copper tap water samples collected during initial monitoring in 1992. Exhibits 1-3 and 1-4 show lead and copper monitoring results for 1993. These data indicate that the action level for lead was not exceeded, but the action level for copper was exceeded during monitoring in 1992 and 1993. Since the action level for copper was exceeded, Auburn was required to comply with additional sampling requirements including source water lead and copper and corrosion-related water quality parameters. Auburn was not required to initiate a public education program because the action level for lead was not exceeded.

Table 1-2
Auburn Water System
Summary of Lead and Copper Monitoring Results*

	1992 Monitoring		1993 Monitoring	
Parameter	**Lead**	**Copper**	**Lead**	**Copper**
USEPA 90th Percentile Action Level (mg/L)	0.015	1.3	0.015	1.3
Auburn 90th Percentile Results (mg/L)	0.006	1.57	0.006	1.5
Number of Samples	60	60	60	60
Range (mg/L)	0.002 - 0.015	0.02 - 5.85	<0.002-0.013	0.01 - 3.5
Samples Exceeding Action Level (Percent)	0	15	0	17
Was the Action Level Exceeded?	No	Yes	No	Yes

** Standing tap water samples*

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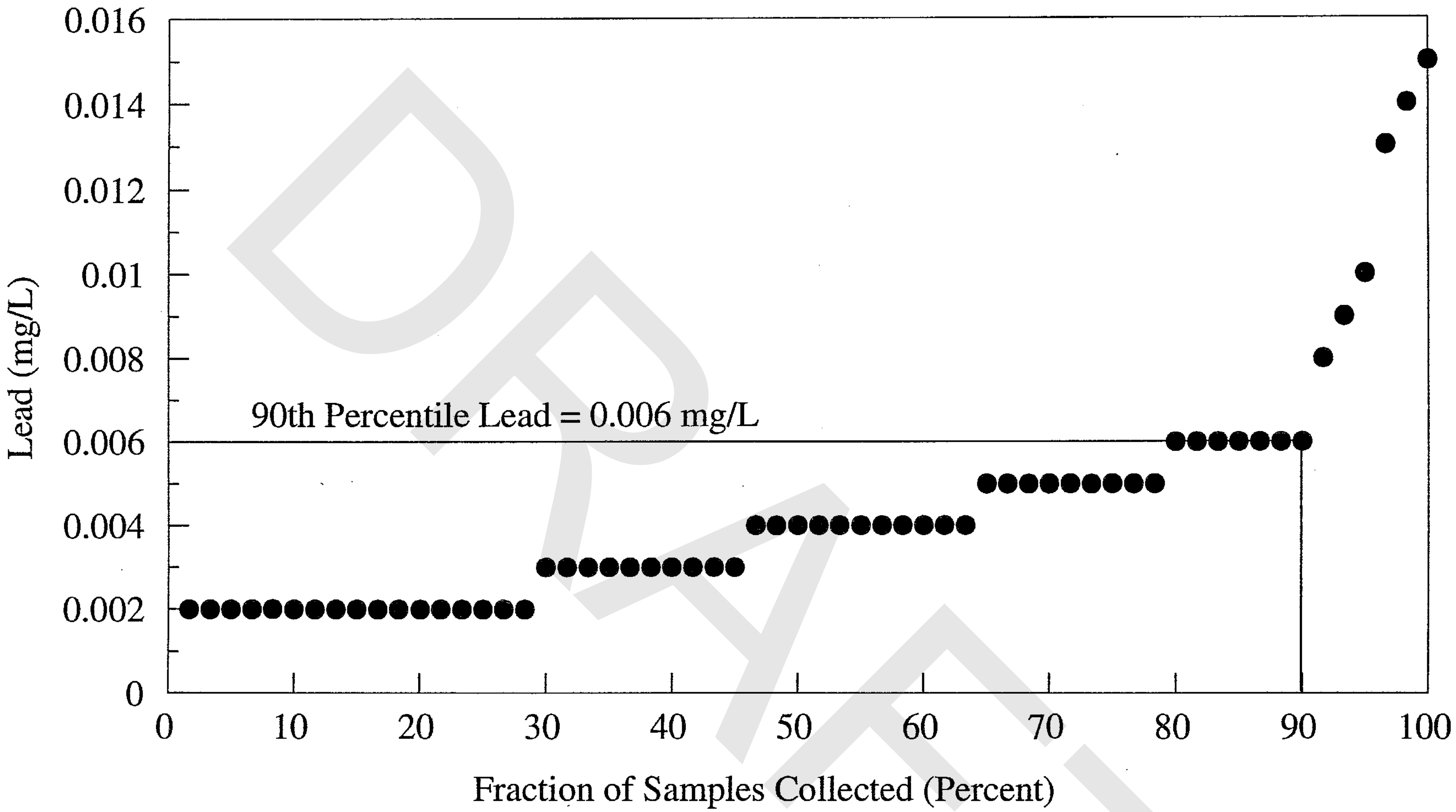

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Exhibit 1-1

Auburn Water System
Monitoring for Lead and Copper Rule - 1992 Lead Results

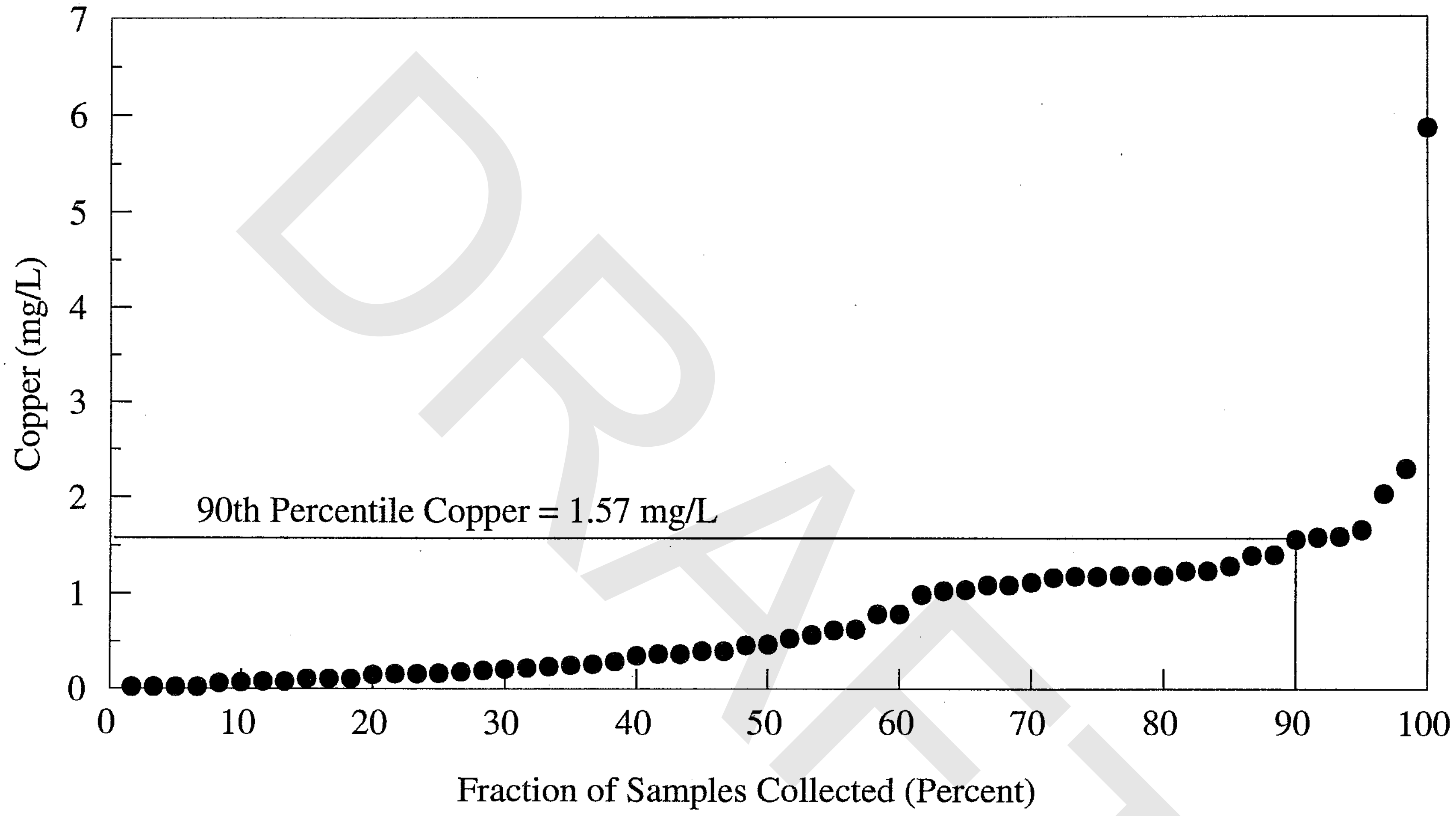

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Exhibit 1-2

Auburn Water System
Monitoring for Lead and Copper Rule - 1992 Copper Results

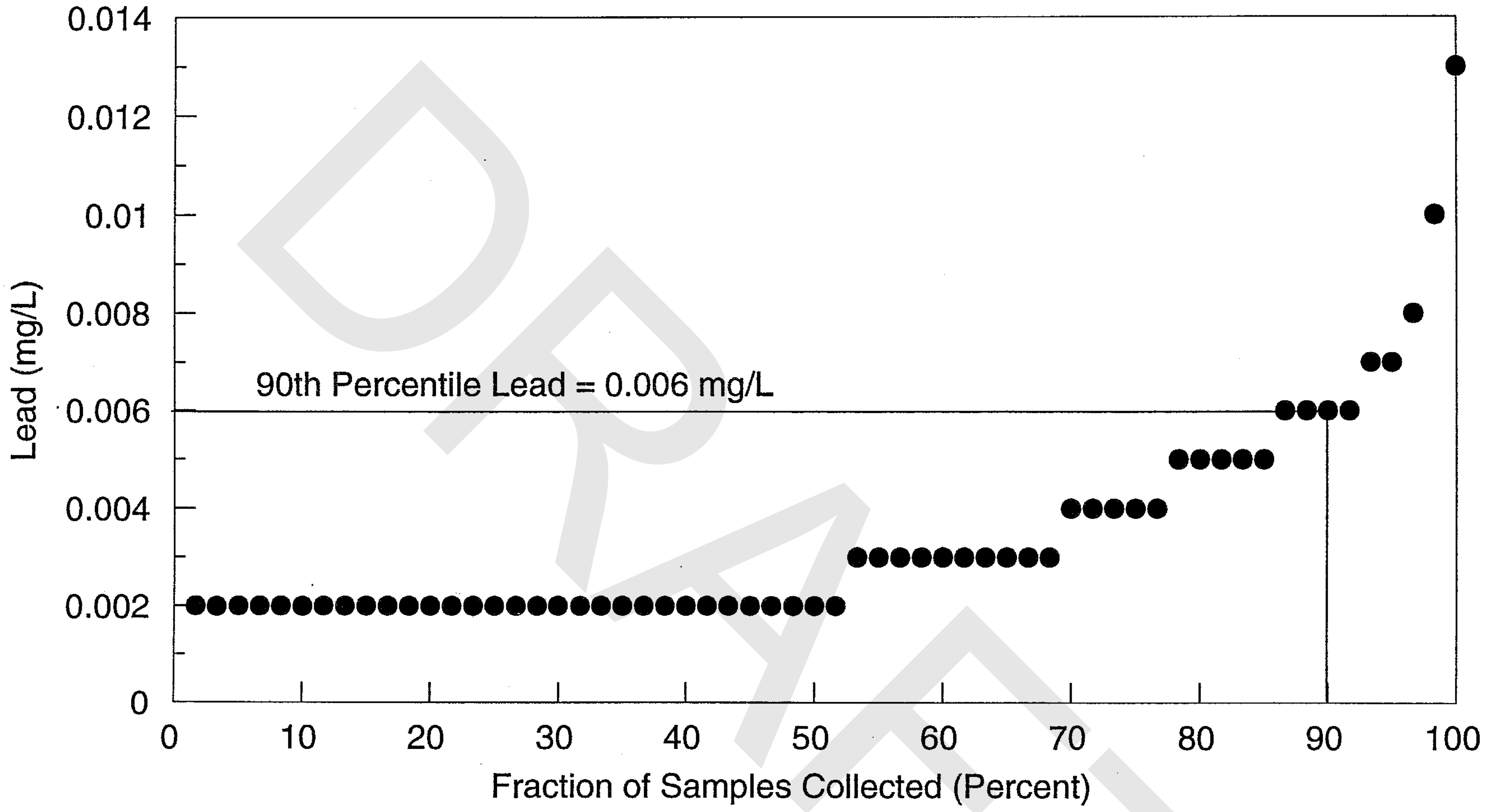

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Exhibit 1-3

Auburn Water System
Monitoring for Lead and Copper Rule - 1993 Lead Results

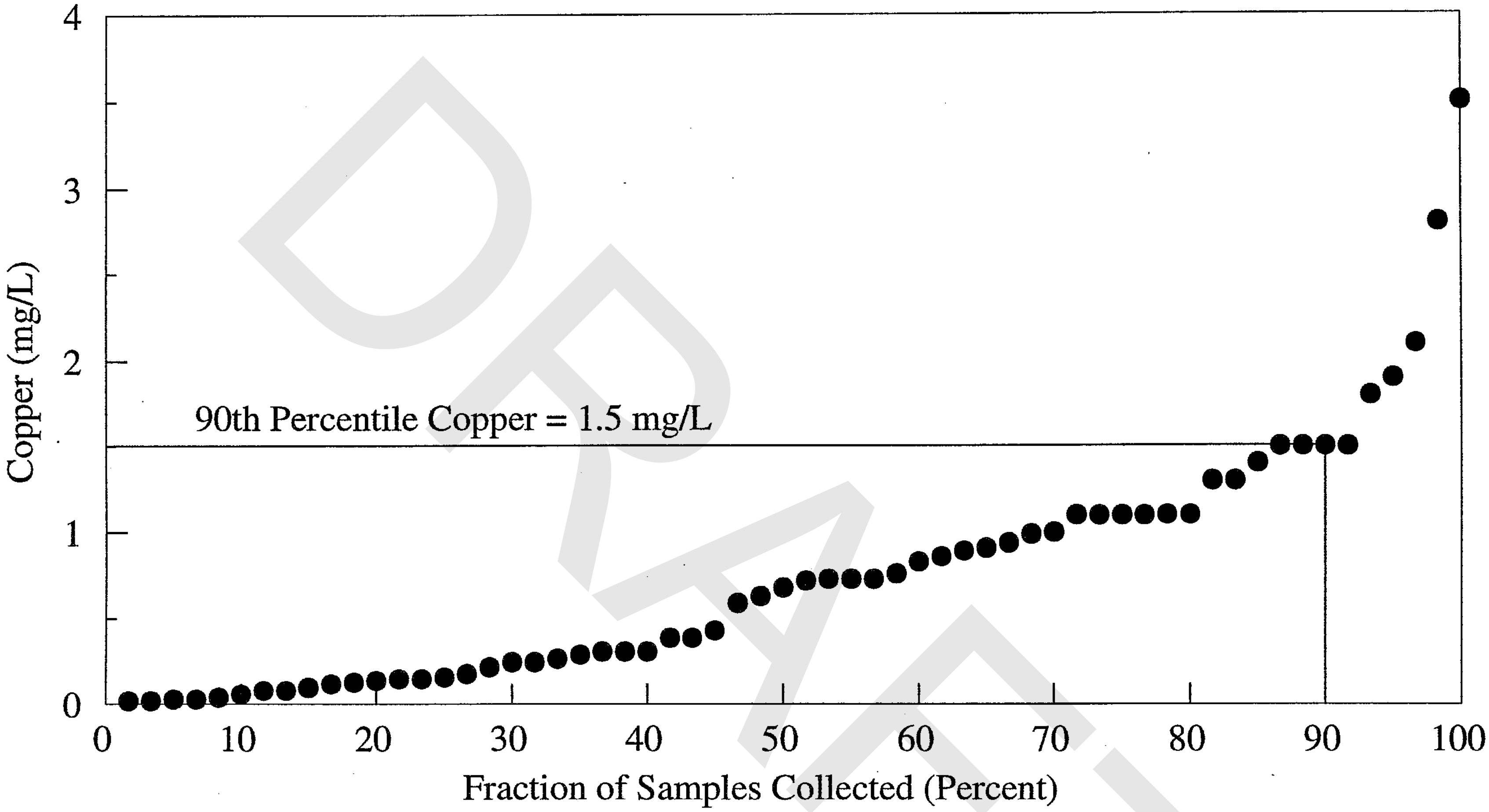

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Exhibit 1-4

Auburn Water System
Monitoring for Lead and Copper Rule - 1993 Copper Results

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Section 2
Review of Existing Information

2.1 Water System Facilities

The Auburn water system encompasses approximately 20 square miles in the Auburn city limits and 5 square miles within the Lea Hill area of unincorporated King County (Exhibit 2-1) The average daily demand is approximately 7 million gallons and the historical peak day demand is 15 million gallons.

2.1.1 Sources

A summary of each source currently operated by the City of Auburn is included on Table 2-1. The water supply for the Auburn system is obtained from two springs and seven wells. The total production capacity of the system is 22.4 million gallons per day (MGD). During lead and copper monitoring in 1992 and 1993, approximately 50 percent of production was obtained from the Coal Creek springs and the remainder was obtained from Wells 1, 2, 4, and 5. Chlorination facilities at the West Hill springs source were being moved in 1992 and therefore monitoring was not conducted at this site. Currently, the West Hill spring source is operational. Auburn is planning to develop new sources (Wells 6 and 7) to meet increased demands in the future.

In addition to sources that supply the Auburn system, the City operates one well for the Hidden Valley community. This well was tested during monitoring for the LCR, but the water from the Hidden Valley source does not enter the Auburn distribution network.

Water which is obtained from Coal Creek springs, West Hill springs, and Wells 1, 2, 4, 5, and 5A generally is produced continuously on an on-call basis. Wells 3A and 3B exhibit high levels of iron and manganese and generally are used only during peak demand periods.

2.1.2 Treatment

The Coal Creek and West Hill springs currently are disinfected on a continuous basis with gaseous chlorine. The free chlorine residual in the distribution system typically ranges from 0.1 to 0.8 mg/L. For the Coal Creek springs, injection occurs at a chlorination station located downstream of the overflow manhole. For the West Hill springs, injection occurs in the 10-inch

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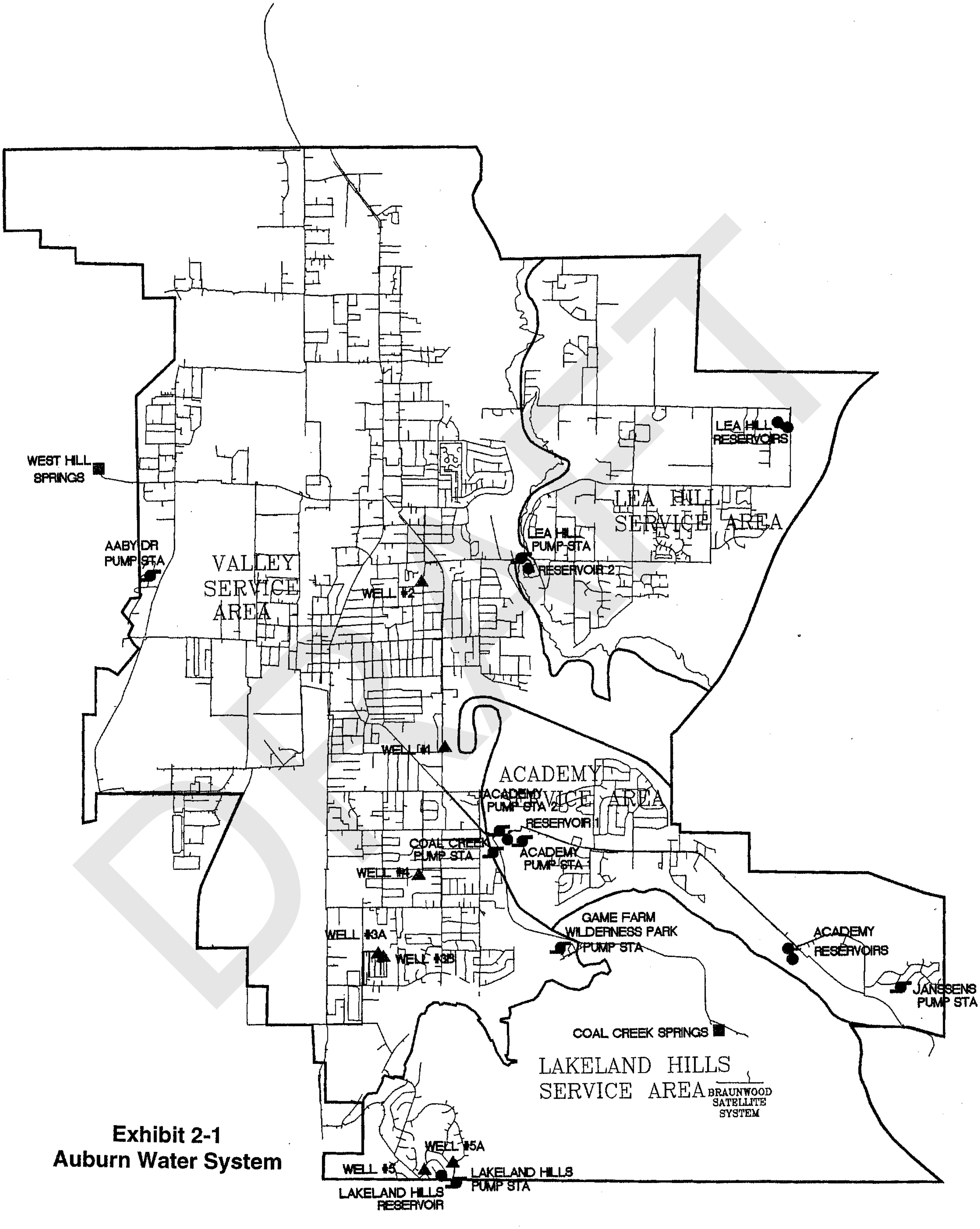

Exhibit 2-1
Auburn Water System

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Table 2-1
Auburn Water System
Summary of Water Sources, Use, Treatment, and Known Water Quality Concerns

System Name	DOH ID	Production Capacity		Estimated Fraction of Production During Lead and Copper Monitoring (Percent)		Frequency and Duration of Use	Pressure Zones Served	Treatment	Known Water Quality Concerns
		(gpm)	(MGD)	1992 Monitoring	1993 Monitoring				
Coal Creek Springs	S01	2,990	4.3	51.4	46.8	Continuous	Valley, Lea Hill, and Academy	Gaseous chlorine injection at the intake.	Currently being evaluated for GWUI.
West Hill Springs	S02	486	0.7	0	0	Continuous	Valley and Lea Hill	Gaseous chlorine injection into 10-inch line at 15th Street NW.	Currently being evaluated for GWUI.
Well 1	S03	2,100	3.0	22.3	27.6	Continuous	Valley and Lea Hill		
Well 2	S04	3,000	4.3	9.6	10.8	Continuous	Valley and Lea Hill		VOCs have been detected since 1990, but less than MCLs.
Well 3A	S05	1,500	2.2	0	0	Peak demand periods only	Valley and Lea Hill	Chlorination facilities are available, but currently are not used.	Iron and manganese levels greater than secondary MCLs.
Well 3B	S08	1,500	2.2	0	0	Peak demand periods only	Valley and Lea Hill	Chlorination facilities are available, but currently are not used.	Manganese levels greater than secondary MCL.
Well 4	S06	3,000	4.3	14.9	13.4	Continuous	Valley, Lea Hill, and Academy		
Well 5	S07	850	1.2	1.8	1.4	Continuous	Lakeland Hills		Radon level >300 pCi/L.
Well 5A	S09	167	0.2	0	0	Continuous—back up for Well 5	Lakeland Hills		Radon level >300 pCi/L.
Hidden Valley[1]	S01	20	0.03	–	–	Continuous	Hidden Valley		
		15,613	**22.4**	**100**	**100**				

[1] *Hidden Valley is a satellite system which is operated by the City of Auburn, but it is not connected to the Auburn distribution system.*

Continuous = On-line and available for use on demand; GWUI = Ground water under the influence of a surface water as defined by the Surface Water Treatment Rule; VOCs = Volatile organic chemicals; MCL = Maximum contaminant level

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transmission line before the first customer at 15th Street NW. Chlorination facilities are available at Wells 3A and 3B, but they currently are not used.

In addition to inactivating microorganisms in the Auburn system, disinfection with chlorine can reduce pH and alkalinity, increase corrosion potential, and increase the concentration of trihalomethanes in the Auburn system. The optimal corrosion control treatment alternative which is selected for the Auburn system will consider these effects on source water quality.

2.1.3 Service Areas

The Auburn system is comprised of four major service areas referred to as the Valley, Academy, Lea Hill, and Lakeland Hills service areas. The Valley service area is the oldest and largest service area which contains the majority of commercial, industrial, and residential customers. Major industrial customers are located in this service area and they include Boeing (1.35 MGD), Auburn General Hospital (0.037 MGD), and BP Chemicals (0.013 MGD).

The Academy service area was constructed in the early 1960s and is the second largest service area based on consumption. It is located southeast of the Valley service area. The Lea Hill service area was constructed in the mid-1960s and is considered the third largest service area of the Auburn system. It is located east of the Valley service area. The Lakeland Hills service area was constructed in the early 1980s and is located south of the Valley service area. Under normal conditions, Lakeland Hills operates independent of the rest of the Auburn system.

Water which is produced from the Coal Creek springs is discharged to the Valley, Lea Hill, and Academy service areas. Water produced from the West Hill springs and Wells 1, 2, 3A, 3B and 4 are discharged to the Valley and Lea Hill service areas. Thus, customers located in the Valley and Lea Hill service areas generally receive water which consists of a blend of Coal Creek springs, West Hill springs, and Wells 1, 2, and 4 (and Wells 3A and 3B if needed to meet peak demands). Customers in the Academy service area receive water from Coal Creek springs and Well 4. Customers in Lakeland Hills receive water from Wells 5 and 5A.

2.1.4 Service Lines and Building Plumbing Conditions

Customer service lines in the Auburn system are made up of approximately 20 percent copper, 35 percent galvanized steel, and 45 percent polyethylene or polybutylene material. Home and/or building plumbing failures are not common in the Auburn service area. However, when they do occur, common

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failure types include leaks at connections of dissimilar plumbing material. Approximately 100 service connections in the Auburn system have lead goosenecks, which currently are being replaced by the City.

2.1.5 Distribution System Piping Conditions and Storage Reservoirs

Auburn's water transmission and distribution system includes more than 195 miles of pipeline. Pipe size varies from 4 to 30 inches, with 8-inch and 12-inch pipe being the predominant pipe sizes. More than half of the distribution system is ductile iron pipe. Approximately 76 miles of pipe are cast iron and mostly lined. Approximately 5 miles of pipe are unlined asbestos cement. A summary of pipe material and length is included on Table 2-2.

Table 2-2
Auburn Water System
Pipe Material and Length

Pipe Material	Length of Pipe (Mile)	Fraction of Total Pipe (Percent)
Cast Iron (approximately 50 percent lined)	75	39
Ductile Iron	113	58
Steel (unlined)	0.03	–
Asbestos Cement (unlined)	4.6	2
Concrete Pressure	2.1	1
Total	**195**	**100**

Lined cast iron and asbestos cement piping materials generally are considered to be in fair to good condition. There is no evidence of tuberculation in unlined steel or cast iron pipe. Currently, water mains are flushed on an as needed basis or in response to customer inquiries. Auburn operates seven covered reservoirs, which are constructed of steel or concrete and contain a total capacity of 14.6 million gallons. There are no uncovered reservoirs in the Auburn system.

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2.2 Water Quality Data

Existing data and information regarding Auburn water quality were obtained from the following sources:

☐ Lead and copper monitoring results for samples collected from taps—December 1992 and June 1993;

- ☐ Water quality parameters monitoring results for samples collected at points of entry and within the distribution system—September 1992, October 1992, April 1993, and June 1993;
- ☐ Regulatory physical and inorganic chemical analyses—1986 through 1994;
- ☐ Regulatory synthetic organic chemical analyses—1988 through 1993;
- ☐ Corrosion control information survey—1994; and
- ☐ Personal communication with Auburn representatives—1993 and 1994.

Source water quality, treatment, distribution effects, customer inquiries, and other regulatory compliance issues are discussed below.

2.2.1 Source Water Quality

Source water quality data that were collected during lead and copper monitoring in 1992 and 1993 are included in Appendix A and summarized on Tables A-1 and A-2. Source water quality parameters tested included pH, temperature, alkalinity, calcium, and conductivity. For the purpose of comparing the water quality characteristics of the Auburn sources, an average value was calculated for each water quality parameter based on these data. The results are summarized on Table 2-3.

Table 2-3
Auburn Water System
Average Source Water Quality Parameters*

Parameter	Well #1	Well #2	Well #3A	Well #3B	Well #4	Well # 5[a]	Coal Creek Springs	Hidden Valley[b]
DOH Source ID #	S03	S04	S05	S08	S06	S07	S01	S01
pH	6.39	6.44	6.59	6.72	6.30	6.81	6.49	6.54
Temperature (°C)	11.5	11.7	11.25	11.1	10.8	9.7	10.6	9.9
Alkalinity (mg/L as $CaCO_3$)	64	95	94	96	58	71	46	66
Calcium (mg/L as $CaCO_3$)	59	63	42	48	44	38	30	42
Conductivity (μmho/cm)	178	226	183	190	144	150	112	136

* *Average based on samples collected at the point of entry for each source during monitoring for the Lead and Copper Rule in 1992 and 1993 (Appendix A). During initial monitoring for the Lead and Copper Rule, chlorination facilities were being moved and monitoring was not conducted at West Hill springs.*

[a] *Well #5A typically is used as a backup for Well #5.*

[b] *Water from the Hidden Valley source does not enter the Auburn distribution network.*

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The data on Table 2-3 indicate the similarity of the Auburn sources. The average pH for the sources ranges from 6.30 to 6.81. These values are all designated by USEPA to be low pH values (Table 2-4). The average alkalinity for the sources ranges from 46 to 96 mg/L as $CaCO_3$. These values generally fall within the USEPA range for moderate alkalinity, with the exception of the Coal Creek springs which falls within the range for low alkalinity. The average calcium concentrations range from 30 to 63 mg/L as $CaCO_3$. These values fall within the low to moderate ranges, with the Coal Creek springs exhibiting the lowest calcium concentration.

Table 2-4
USEPA Designated pH, Alkalinity, and Calcium Categories

	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)
Low	<7.5	<50	<50
Moderate	>7.5 - 9	50 - 150	50 - 150
High	>9	>150	>150

Source: USEPA Guidance Manual Volume II: Corrosion Control Treatment, 1992

2.2.2 Distribution Water Quality

Water quality data were collected in the distribution system during lead and copper monitoring in 1992 and 1993 (Exhibit 2-2). Water quality parameters included pH, temperature, alkalinity, calcium, and conductivity. For the purpose of comparing distribution samples to Auburn sources, average values were calculated for each water quality parameter and the results are summarized on Table 2-5.

The data on Table 2-5 indicate that the average water pH in the distribution system is low and ranges from 6.4 to 6.6. These average pH values are similar to the average pH values calculated for Auburn source water (Table 2-3). The average alkalinity of the water in the distribution system ranges from 48 to 80 mg/L as $CaCO_3$ and the average calcium concentration ranges from 38 to 72 mg/L as $CaCO_3$. These average water quality characteristics are similar to Auburn sources and fall within the range of low to moderate alkalinity and calcium concentrations per USEPA classifications (Table 2-4). These data indicate that Auburn water is corrosive to copper and needs treatment (see Section 3, Causes and Effects of Corrosion).

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Exhibit 2-2
Auburn Water System Monitoring Sites for the Lead and Copper Rule

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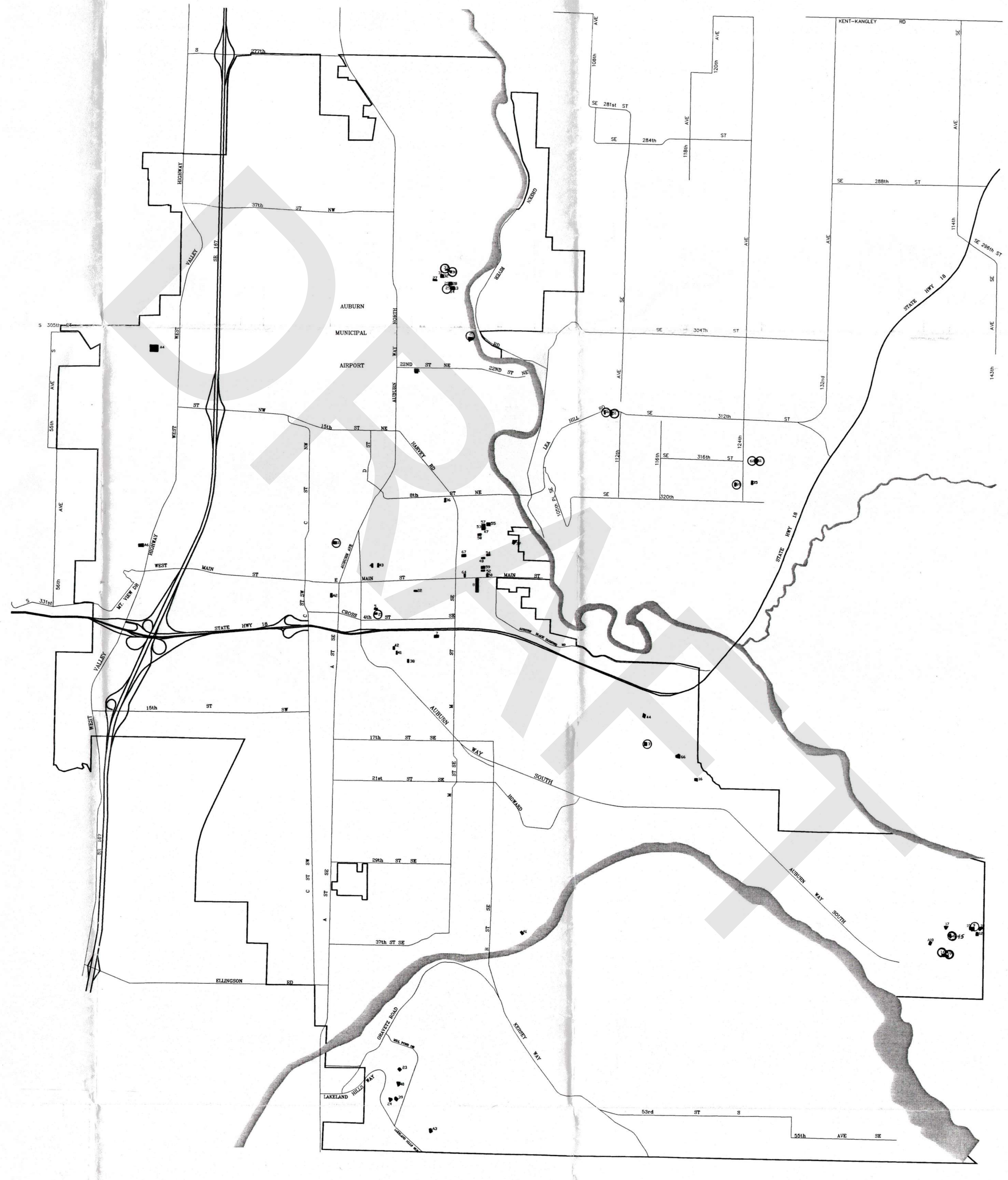

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City of Auburn Washington

CITY OF AUBURN
PUBLIC WORKS DEPARTMENT
GEOGRAPHIC INFORMATION SYSTEM

CITY OF AUBURN
CORROSION CONTROL STUDY

LEGEND
- ● LOCATION OF TEST SITE
- ◉ LOCATION WITH COPPER LEVEL HIGHER THAN 1.3

MAY '95

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Table 2-5
Auburn Water System
Average Distribution System Quality Parameters*

Parameter	A-5	A-10	A-3	B-4	B-6	B-8	C-3	C-7	D-1	D-6
pH	6.4	6.4	6.6	6.5	6.4	6.5	6.4	6.5	6.5	6.5
Temperature (°C)	15.6	14.3	15.8	15.1	15.4	16.2	16.7	15.8	14.4	15.0
Alkalinity (mg/L as $CaCO_3$)	56	56	60	68	70	56	70	80	53	48
Calcium (mg/L as $CaCO_3$)	40	48	40	52	46	45	72	63	39	38
Conductivity (µmho/cm)	124	145	155	175	149	132	191	201	120	116

* *Average water quality parameters are based on samples collected in the distribution system during monitoring for the Lead and Copper Rule in 1992 and 1993. Sample collection sites are specified below.*

A-5	*1913 37th Street SE*
A-10	*108 South Division*
A-3	*1201 57th Drive SE*
B-4	*1517 22nd Street NE*
B-6	*27736 80th Avenue South*
B-8	*212 Hi Crest*
C-3	*32721 111th Place SE*
C-7	*30211 104th Avenue SE*
D-1	*3022 Scenic Drive*
D-6	*5824 35th Way SE*

2.2.3 Customer Inquiries

The most common types of customer inquiries include red/rusty water, green stains on fixtures, low pressure/flow, and taste and odor. Red/rusty water inquiries typically occur when work is done on old pipes. Inquiries regarding blue/green stains typically occur for new homes and may be associated with improper grounding of electrical service. A study recently completed by AWWARF (1994) concluded that water quality, stray current, lightning, fixtures, and construction practices all contribute to copper concentration in home plumbing. Low pressure/flow inquiries typically are associated with changes in system operations (e.g., adjustments to pressure reducing valves) as well as older, clogged interior systems. And finally, taste and odor inquiries typically occur as a result of stagnant water in dead end zones.

2.2.4 Water Quality Data for Other Regulations

Water quality data currently are being collected for the Coal Creek and West Hill springs to confirm that these sources are ground water sources and not ground water under the direct influence of a surface water (GWUI). If these wells are classified as GWUI, then Auburn would be required to operate them per the requirements of the Surface Water Treatment Rule (SWTR). A final determination regarding the classification of these sources will be made by DOH in the future.

Water produced from Wells 3A and 3B exhibit iron and manganese levels that exceed the secondary MCLs of 0.3 mg/L and 0.05 mg/L, respectively. Water quality data collected from these wells in 1989 through 1994 indicate iron levels which range from 0.04 to 1.22 mg/L and manganese levels which range from 0.112 to 0.463 mg/L. As a result of these water quality characteristics, wells 3A and 3B are used only during peak demand periods. If these wells were used for normal operations, then the City may need treatment to reduce iron and manganese levels below secondary MCLs.

Since 1990, water analyses for samples collected at Well 2 have detected several volatile organic chemicals (VOCs). The data have ranged from 0.7 to 2.6 µg/L, which are below drinking water MCLs. Data and information have been studied by DOH and deemed that no further study is needed, only quarterly monitoring is required.

In 1994, samples were collected from each source and analyzed for radon-222. Results obtained for Coal Creek springs and Wells 1, 2, 3A, 3B and 4 indicate radon levels that range from 205 to 285 pCi/L. Water from these sources typically are discharged to the Valley, Lea Hill, and Academy service areas. Results obtained from Wells 5 and 5A indicate radon levels of 710 and 825 pCi/L. Water from these wells are discharged to the Lakeland Hills service area.

Existing data indicate that total trihalomethane levels in the Auburn system range from non-detectable to 31 µg/L. The impacts of other SDWA regulations are discussed in Section 5 of this report.

2.3 Source Water Treatment Needs

According to the requirements of the LCR, medium-sized public water systems which exceeded an action level during regulatory monitoring at-the-tap were required to determine the concentrations of lead and copper at each point of entry (POE) to the distribution system. POE samples were to be collected within six months of exceeding an action level. Because Auburn exceeded the action level during the first round of monitoring (July to December 1992), lead and copper samples were collected from the POEs of Auburn's sources. Samples also were collected from the Auburn POEs during the second round of monitoring in 1993.

Source water sampling was required to determine if the source of supply was contributing more copper than the regulatory action level, or if copper levels in the source combined with levels measured at-the-tap were resulting in the action level

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exceedance. Source water treatment will be required, recommended, or unnecessary, based on the amount of copper measured at the POE.

Results of POE sampling for copper during initial tap water monitoring in 1992 are presented in Table 2-6 below.

Table 2-6
Auburn Water System
Lead and Copper POE Monitoring Results

System Name	DOH ID	1992 Monitoring		1993 Monitoring	
		Lead (mg/L)	**Copper (mg/L)**	**Lead (mg/L)**	**Copper (mg/L)**
Coal Creek Springs	S01	<0.02	<0.02	<0.002	<0.02
West Hill Springs	S02	NA	NA	NA	NA
Well 1	S03	<0.002	<0.02–0.06	<0.002	0.004–0.02
Well 2	S04	<0.002	0.04–0.15	<0.002	<0.02
Well 3A	S05	<0.002	0.05	<0.002–0.005	<0.02–0.04
Well 3B	S08	<0.002	<0.02–0.15	<0.002	<0.02
Well 4	S06	<0.002	<0.02	<0.002	<0.02
Well 5	S07	<0.002	<0.02	0.002	<0.02
Well 5A	S09	NA	NA	NA	NA
Hidden Valley	S01	<0.004	<0.02	<0.002	<0.02

NA = Not Available

As discussed previously, the West Hill springs source was not operational during initial lead and copper monitoring due to facilities modifications. The sample collected from Well 3A on September 29, 1992 was lost and no sample was collected from Well 5A because it was constructed after the initial monitoring period for the LCR. Table 2-7 presents USEPA's guidelines regarding source water treatment requirements for lead and copper.

Table 2-7
USEPA Source Water Treatment Guidelines for Systems Exceeding an Action Level

Source Water Treatment Guidelines	Lead, mg/L	Copper, mg/L
Not Necessary	<0.005	<0.2
Optional	0.005–0.010*	0.2–0.8
Recommended	0.010–0.015	0.8–1.3**
Required	>0.015	>1.3

* *Source water treatment is recommended if the corrosion treatment is at or near optimal and the lead action level is still exceeded.*

** *If the copper action level is exceeded, source water treatment may be required when corrosion control treatment is unlikely to reduce copper levels below the action level.*

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Comparison of Auburn's POE lead and copper levels (Table 2-6) to regulatory guidelines established by the USEPA (Table 2-7) indicate that source water treatment for reducing lead or copper levels is not necessary. Auburn's POE lead and copper levels are less than 0.005 mg/L and 0.2 mg/L, respectively. Therefore installation of a treatment technology to remove copper at the source of supply probably would not decrease metals uptake at the tap. However, because the copper action level of 1.3 mg/L was exceeded during at-the-tap monitoring, this assessment is part of the process of conducting a desktop evaluation as required by USEPA to determine the optimal treatment technique for minimizing copper and the potential for lead corrosion in its service area.

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Section 3
Causes and Effects of Corrosion

This portion of the report summarizes the probable causes of copper corrosion within Auburn's service area. The causes of corrosion can be divided into two categories: (1) susceptible materials (especially unlined metallic piping and home fixtures) and (2) aggressive water conditions. Corrosion and metals leaching can potentially cause undesirable health and aesthetic (e.g., blue-green stains on plumbing fixtures) impacts on water quality as well as decrease plumbing material life. Leaching increases the metal concentration in the water through the mobilization of metals when contacted with an aggressive water.

Various physical properties of the pipe, such as size, configuration, workmanship, and water quality can also accelerate or inhibit corrosion of piping materials. Source water quality parameters are most often targeted as the cause of corrosion, therefore corrosion control studies focus on certain parameters that can be changed with chemical addition. Water treatment practices should also be considered since disinfectants can significantly alter source water quality and act as oxidizing agents. These potential causes of corrosion with respect to Auburn's system are reviewed in this section.

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3.1 Corrosion of Materials of Concern

Based on water quality data and preliminary tests completed by Auburn under the LCR, some corrosion of piping and plumbing materials is presently occurring in Auburn's service area. Typically, the small diameter, unlined metallic portions of piping systems are at most risk of deterioration and/or leaching metal contaminants into the water. These pipe portions are found in service lines and in premise piping. The larger diameter pipelines that are lined with cement mortar are protected because the aggressive water does not normally gain access to the metal piping. The materials most susceptible in Auburn's service are shown in Table 3-1.

The wide variety of materials present in Auburn's distribution system and the variability of corrosion-related properties associated with each material prevents the development of a corrosion control strategy that addresses each type of piping material equally. Therefore, the most critical materials should be targeted in corrosion optimization studies.

Table 3-1
Auburn Water System
Materials Susceptible to Corrosion in the Service Area

Materials	Location/ Appurtenances	Type of Concern	Priority of Concern
Copper Pipe	Location: Home Plumbing and Service Lines	Health: Copper Release Aesthetics: Blue Green Stains	High
Brass and Lead Solder	Location: Home Plumbing, Fixtures	Health: Lead and Copper Release Aesthetics: Blue Green Stains	Medium
Galvanized Pipe	Location: Home Plumbing and Service Lines, Small Distribution Piping	Health: Zinc Aesthetic: Red/ Rusty Water Economic: Loss of Hydraulic Capacity, Pipe Failures	Medium
Unlined Iron and Steel	Location: Distribution System	Aesthetic: Red/ Rusty Water Economic: Loss of Hydraulic Capacity, Pipe Failures	Low
Asbestos Cement	Location: Distribution System	Health: Asbestos Fiber Release Economic: Dissolution of Pipe	Low

3.1.1 Copper Piping

Copper service lines and household copper plumbing systems are susceptible to both corrosion and metals leaching. Copper levels in standing samples exceeded the 1.3 mg/L action level indicating that corrosion of copper pipe is occurring in Auburn's system. Approximately 20 percent of the retail customer service lines is copper plumbing. Thus, the main source of copper in drinking water most likely is the copper pipe itself.

Corrosion control measures that address copper uptake will most likely have a positive effect on the aesthetic quality of the drinking water in terms of decreasing the occurrence of green stains on plumbing fixtures, possibly decreasing taste episodes, and most likely will lessen the economic impacts of corrosion due to enhanced copper pipe life spans.

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3.1.2 Brass and Lead Solder

Brass fixtures and lead solder can both serve as a significant source of lead in drinking water. The galvanic reaction between lead solder and copper pipe can result in significant amounts of lead release (AWWARF, 1990).

Brass is mainly composed of copper and is commonly found in valve parts, faucets, and water meters. Brass can contribute significant amounts of both lead and copper to the first flush samples through metal release. The brasses most-commonly used as household fixtures contain 1.5 to 7.5 percent lead. Brass can be termed "lead free" yet still contain up to 8 percent lead according to USEPA guidelines. A 1988 survey conducted for the American Water Works Service Company estimated that 33 percent of the mass of lead in 1.0-liter samples was contributed by lead-containing brass faucet fixtures (AWWARF, 1990). Although Auburn was below the action level for lead, it is imperative to determine the impact of corrosion control optimization techniques on lead solubility as well as on copper solubility.

3.1.3 Galvanized Steel Piping

The zinc coating on galvanized pipes initially protects the steel pipe from corrosion. Zinc levels have not been measured in the Auburn distribution system. Typically rusty/red water complaints indicate that the zinc has been sacrificed and corrosion of the steel pipe is occurring. Not only does corrosion of galvanized pipe impact the aesthetic quality of the water, it can serve as a potential source of lead leaching as well, since lead is known to be an impurity in galvanized pipe production. Galvanized piping comprises 35 percent of service line connections in the Auburn system and therefore it will be desirable to select a corrosion control technique that does not increase corrosion of galvanized piping materials.

3.1.4 Unlined Iron and Steep Pipe

Unlined cast iron and steel pipe can be very susceptible to corrosive attack. Internal corrosion of iron distribution pipes is generally in the form of pits and tubercles, with pipe plugging rather than leakage being the major problem. Although this phenomena reduces the risk of pipe failure resulting from leakage, leaching of iron into the water can adversely impact water quality (AWWARF, 1985). Corrosion control strategies involving pH adjustment for lead and copper potentially may increase the water's aggressiveness to ferrous pipe materials because the pH of minimum solubility is lower for iron and steel than for lead and copper. Although unlined iron and steel pipe represent 19 percent of the Auburn system, the recommended corrosion control treatment should not significantly increase corrosion of these piping materials.

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3.1.5 Asbestos Cement Piping

Asbestos is a component of asbestos cement (AC) pipe which provides the ability of the pipe to withstand high pressures. A number of studies have shown that corrosive waters can cause dissolution of the cement binder and release asbestos fibers into the water. Concern about asbestos fibers in drinking water initially arose from the association of air-borne asbestos exposure and lung cancer. Medical debate over the health risk of ingesting asbestos fibers is ongoing. DOH has set an MCL of 7 million asbestos fibers over 10 microns in length per liter. The selection of a corrosion control treatment should decrease the aggressiveness of Auburn water towards AC piping.

3.2 Potential Causes of Corrosion

3.2.1 Water Quality Parameters

Source water quality parameters that most likely affect the corrosivity of Auburn's water include the following:

- ☐ Low pH,
- ☐ Low-Moderate Alkalinity,
- ☐ Influence of the Carbonate System, and
- ☐ Low-Moderate Mineral Levels.

Information available in literature and past experiences of other utilities indicate that the occurrence of all the above conditions often results in water that is aggressive to various materials commonly found in distribution and premise piping systems.

pH Levels

pH and alkalinity levels have the greatest impact on metals uptake from internal pipe materials. pH controls metals solubility and affects chemical reaction rates. Table 3-2 includes a summary of optimum pH levels for minimum metals solubility for common pipe material.

Table 3-2
Theoretical Optimum pH Levels for Minimum Metal Solubility

Material	Optimum pH
Lead	9 - 9.5
Copper	8 - 9
Steel	7.5
Zinc	7.5
Galvanized Pipe	7.5 - 8

From: Internal Corrosion of Water Distribution System (AWWARF and DVGW, 1985).

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pH levels can affect copper corrosion in low-moderate alkalinity and calcium water such as Auburn (see for example Exhibit 3-1). In addition to increasing the solubility of normally protective copper oxides, low pH increases the transport velocity of hydroxyl ions away from the corroding surface, which is a rate-controlling step. Uniform corrosion of cold water copper piping dramatically increases as the pH decreases below 7.0. pH is also an important factor in hot water recirculating systems which are often used in high-rise and building plumbing systems. Corrosion pits in these systems are typically narrow and deep, and can perforate the plumbing in 10 to 15 years. The range of pH (6.1–7.4) measured from individual sources in Auburn's system (see Appendix A) indicates that the water is corrosive to copper.

Low pH in Auburn's supply also potentially can increase the solubility of lead from lead-based solder and from brass fixtures. Studies have shown that pH variation over the range of 6 to 9.5 has little direct effect on the corrosion of steel and iron. pH has an indirect effect on the corrosion rate of these metals because it can influence the potential for protective scale formation. Low pH appears to increase the corrosion rate of zinc; however, very few studies have investigated the contribution of pH on zinc corrosion. A report by Bachle et al. (1981) indicated that zinc corrosion rates increased by a factor of 7 to 8 with a decrease in pH from 8 to 7. Other studies have suggested a rapid reduction in the life of zinc coating between pH 7.2 and 7.6. pH levels in Auburn's distribution system are in the range of 6.2 to 7.5. It is likely that pH adjustments will be an important step in decreasing corrosion in Auburn's distribution system.

Although monitoring results for the LCR indicate that Auburn did not exceed the action level for lead, pH adjustment can reduce the possibility of lead (as well as iron and zinc) corrosion in the Auburn system.

Alkalinity Levels

Moderate alkalinity waters have some buffering capability; therefore, significant pH drops usually do not occur during chlorination. Low alkalinity waters are very limited in their ability to form protective $CaCO_3$ scales on piping.

Alkalinity may adversely impact copper corrosion in the Auburn system. According to a survey funded by the Water Industry Technical Action Fund (WITAF) and sponsored by the AWWA Research Foundation, results indicate that utilities that use water which is low in pH generally exhibited higher 90th percentile results for copper with increased alkalinity. The pH conditions for the Auburn's system were lower than the lowest range presented for the WITAF study. This may account for Auburn 90th

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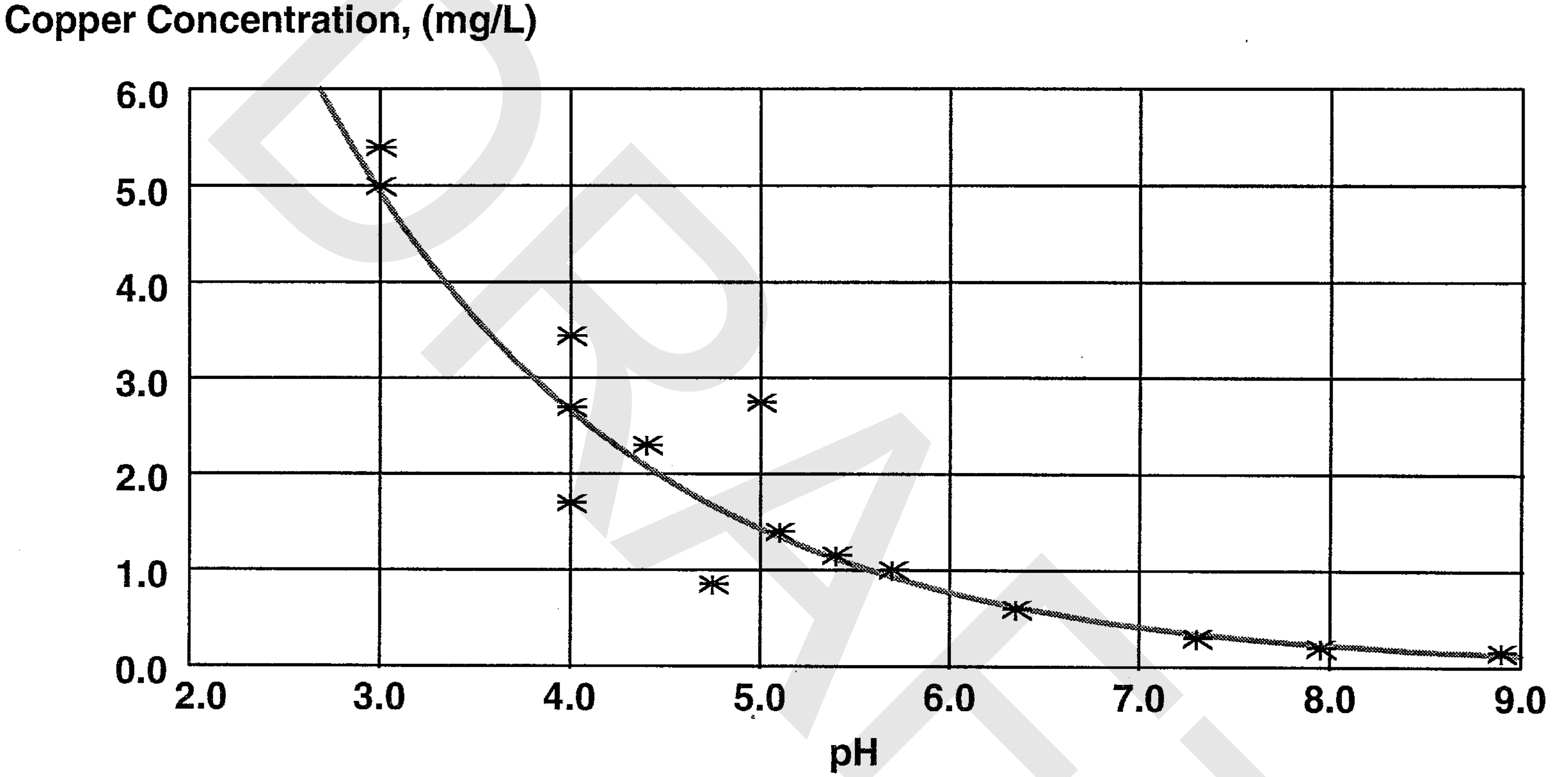

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From: Internal Corrosion of Water Distribution Systems, AWWARF, 1985. Conditions: Water at the desired pH was allowed to flow through 60 feet of new 0.75 inch copper tubing at a rate of 0.5 gallons per minute for 1 hour and then stopped for 16 hours to simulate overnight conditions.

Exhibit 3-1. Effect of pH on the Release of Copper into Solution

percentile copper levels being higher than those reported for comparable alkalinity range.

Influence of the Carbonate System

The carbonate system controls acid-base equilibrium in natural waters. Species that make up the carbonate system (Snoeyink and Jenkins, 1980) include:

- ☐ Gaseous CO_2($CO_{2(g)}$)
- ☐ Dissolved CO_2($CO_{2(aq)}$)
- ☐ Carbonic Acid (H_2CO_3)
- ☐ Bicarbonate (HCO_3^-)
- ☐ Carbonate (CO_3^{-2})
- ☐ Carbonate Containing Solids

It is through reactions with the carbonate system that alkalinity (HCO_3^- and CO_3^{-2}) is imparted to the water (Stumm and Morgan, 1970). The carbonate system controls the interaction of pH and alkalinity for natural water systems. As pH is increased between 7 and 9, the inorganic carbonate species in solution are converted to bicarbonate ion which is the primary buffer in natural waters.

Auburn sources contain approximately 28 to 85 mg/L of free carbon dioxide. This inorganic carbon species can be responsible for maintaining a low pH water. Results are summarized on Table 3-3.

Table 3-3
Auburn Water System
Calculated Free Carbon Dioxide

	Well #1	Well #2	Well #3A	Well #3B	Well #4	Well #5	Coal Creek Springs	Hidden Valley
pH (Standard Units)	6.4	6.4	6.6	6.7	6.3	6.8	6.5	6.5
Alkalinity (mg/L $CaCO_3$)	64	95	94	96	58	71	46	66
Temperature(°C)	11.5	11.7	11.3	11.1	10.8	9.7	10.6	9.9
TDS (mg/L)	110[a]	110[a]	110[a]	110[a]	110[a]	110[a]	110[a]	110[a]
Calculated Free CO_2 (mg/L)	**55[b]**	**85[b]**	**50[b]**	**50[b]**	**60[b]**	**28[b]**	**34[b]**	**48[b]**

a *Estimate based on data provided by USGS (1986) for King County, Washington.*
b *Estimate based on nomograph in Standard Methods (1992).*

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Mineral Levels

Auburn's sources are generally considered low-moderately hard, yet can still be corrosive to galvanized steel, iron, copper, asbestos cement, and lead materials. These waters usually lack the ability to precipitate a protective calcium carbonate scale inside piping without pH adjustment.

3.2.2 Water Treatment Practices

Auburn uses free chlorine as its disinfectant. Although lower pH levels are advantageous in terms of disinfection efficiency, they can be a contributor to corrosion. The effects of disinfection with chlorine on copper corrosion can be summarized as follows (AWWARF and DVGW, 1985):

- ☐ Free chlorine can increase the corrosiveness of water towards copper and its alloys.
- ☐ Copper corrosion is highly dependent on pH levels, with low pH levels causing higher copper corrosion rates. This pH dependency applies in the presence of chlorine.

According to Auburn personnel, a free chlorine residual of 0.1 to 0.8 mg/L is maintained throughout the distribution system to meet disinfection requirements of DOH.

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3.2.3 Physical Water Properties

Physical factors such as water temperature and velocity also can contribute to or inhibit the aggressiveness of water.

Temperature

Corrosion theory predicts that corrosion rates will increase with temperature. Typically, rates of chemical reactions tend to double with each 10°C increase in temperature (AWWARF and DVGW, 1985). The effects of temperature on corrosion are not necessarily material specific; however, temperature effects will vary for different waters.

The temperature of Auburn water varies from approximately 9 to 12°C. Increased temperature can increase the reaction rate for corrosion, shift chemical equilibrium, and affect the solubility of gases. Hot water (30° to 45°C) which is unsaturated with calcium carbonate, is potentially much more corrosive to most premise plumbing than water at cooler temperatures. In Seattle, pitting rates were two to three times greater in hot water pipes compared to cold water pipe. In contrast, warmer temperatures may induce scale formation, thereby reducing corrosivity. Increases in temperature also can drive off corrosive gases such as dissolved oxygen and carbon dioxide.

Based on preliminary chemical equilibrium calculations, the alkalinity and calcium concentration of Auburn water are not sufficient to form a precipitate when the temperature is raised to the range of 30 to 45°C. Thus, warmer temperatures would most likely increase the reaction rate for corrosion and increase the aggressiveness of the water towards home plumbing materials in the Auburn system.

Velocity

Water velocity can enhance corrosion by two general processes. High velocities have the ability to scour protective films and prevent scale formation. Also, high velocities carry more oxygen to the corrosion cell, increasing the corrosion rate, particularly over neutral pH ranges. Velocities in excess of 1.5 feet per second (fps) in hot water circulating systems and/or 6.0 fps in cold water lines increasingly accelerate pitting and corrosion failures.

3.3 Conclusions

Water quality characteristics such as:

- ☐ Low pH,
- ☐ Low to moderate alkalinity,
- ☐ Interactions of the carbonate system at low pHs,
- ☐ Low to moderate hardness, and
- ☐ Relatively high levels of dissolved carbon dioxide

can all contribute to the corrosivity of Auburn's water supply.

Treatment and operational practices (such as pH adjustment and disinfectant dosage) also can affect the level of metals release in the distribution system.

The primary materials of concern in Auburn's distribution system are prioritized below:

- ☐ Copper Pipe—The action level for copper was exceeded during monitoring of homes in the Auburn system per the LCR.

- ☐ Brass Fixtures and Lead Solder—Brass is comprised primarily of copper and may contribute to elevated copper levels in a one liter, first draw sample. Although Auburn did not exceed the action level for lead per the LCR, the corrosive tendency of Auburn water potentially could be a concern for homes equipped with certain brass fixtures and lead solder.

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- ☐ Lined/Unlined Cast Iron—These materials make up a significant portion of the distribution system. Any corrosion control technique developed for copper and lead should not negatively impact corrosion of cast iron piping.

Methods for mitigating likely causes of corrosion in Auburn's system are evaluated in the following sections of this report.

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Section 4
Review of Corrosion Control Experiences

This section includes a review of corrosion control experiences of analogous systems and comparison to the Auburn system. As part of the required corrosion control study, the Washington State Department of Health recommends the following information be included in the discussion of analogous systems:

- ☐ System name
- ☐ Justification of analogous nature including
  - ■ Water quality data
  - ■ Lead and copper sampling results
  - ■ Treatment
  - ■ Plumbing materials
  - ■ System size
- ☐ Description of systems' corrosion studies
- ☐ Lead and copper monitoring results since corrosion control treatment installation

Water utilities located in the Pacific Northwest with water quality and treatment characteristics similar to Auburn have undertaken various approaches to identify and mitigate corrosion and metals release in their systems. Corrosion related water quality parameters for several utilities were reviewed for comparison with Auburn. Analogous systems were selected based on water quality characteristics, system size, treatment, and proximity to Auburn. Three analogous systems were selected with ground water supplies similar to Auburn's ground water sources. The three ground water supplies include the following:

- ☐ Covington Water District, Kent, Washington,
- ☐ City of Vancouver, Washington, and
- ☐ City of Renton, Washington.

Two surface water supplies were selected for comparison to Auburn's spring water sources. The two surface water supplies include the following:

- ☐ City of Seattle, Washington, and
- ☐ Bureau of Water Works, Portland, Oregon.

In addition to Pacific Northwest systems, the results of a national survey of 660 large drinking water systems regarding their experiences with monitoring for the Lead and Copper Rule are discussed and compared to the Auburn system.

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Table 4-1 contains the system name and size, water quality data, treatment, lead and copper monitoring results, and plumbing materials for Auburn and the analogous systems. More specific information for each analogous system is described in detail in the following subsections.

Table 4-1
Water Quality Characteristics for Auburn and Analogous Systems

	Ground Water Supplies				**Surface Water Supplies**	
	Auburn, WA	**Covington, WA**	**Vancouver, WA**	**Renton, WA**	**Seattle, WA**	**Portland, OR**
Source Water	7 Wells 2 Springs	8 Wells	17 Wells	8 Wells 1 Spring	Cedar River Tolt River	Bull Run Watershed
Population	40,000	29,500	108,000	43,000	1,200,000	470,000+
Treatment	Chlorination for springs.	Manganese removal for the Witte Road well field.	Chlorination and fluoridation at all wells, aeration at 50% of supply, Fe/Mn removal at one site.	Disinfection and fluoridation at all wells, inhibitor addition at three wells, aeration at two wells (future).	Disinfection, lime and/or soda ash addition, fluoridation	Disinfection
Source pH	6.3–6.8	6.6–7.6	6.5–7.5	6.3–8.3	7.0 Cedar 6.0 Tolt	6.5 - 7.2
Finished pH	6.4–6.6	6.8–7.8	6.5–7.6 (unaerated) 7.9–8.1 (aerated)	6.0–8.3	8.2	6.5 - 7.2
Source Alk. as $CaCO_3$	46–96	50–77	59–122	40–98	15 Cedar 4 Tolt	7 - 13
Finished Alk. as $CaCO_3$	48–80	50–77	67–160	40–98	23 Cedar 13 Tolt	7 - 13
Disinfectant	Primary–free chlorine Secondary–none	None currently	Primary and Secondary–free chlorine	Primary–free chlorine Secondary–none	Primary and Secondary–free chlorine	Primary–free chlorine Secondary–chloramines
Corrosion Treatment	None currently	None currently	0% aerated in first round. 20% aerated in second round. 50% aerated currently.	Inhibitor for iron corrosion	pH using lime on Cedar, pH and alk. using lime and soda ash on the Tolt	None currently
1st Round 90% Pb, mg/L	0.006	0.006	0.005	0.010	Cedar 0.0148 Tolt 0.0217	0.044
90% Cu, mg/L	1.57	2.9	1.4	3.3	0.31, 0.30	1.8
2nd Round 90% Pb, mg/L	0.006	0.005	0.005	0.006	Cedar 0.0139 Tolt 0.0246	0.053
90% Cu, mg/L	1.5	2.8	1.2	3.8	0.33, 0.54	1.3
LCR Sample Sites	Lead Solder	Lead Solder	Lead Solder	Lead Solder	Lead Solder	Lead Solder

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4.1 Covington Water District, Kent, Washington

The Covington Water District provides drinking water service to approximately 29,500 residential consumers within a service area of 55 square miles. Covington relies primarily on two groundwater sources (Witte Road and Lake Sawyer) which exhibit pH values ranging from 6.6 to 7.6, alkalinity values ranging from 50 to 77 mg/L as $CaCO_3$, and manganese levels ranging from <0.01 to 0.15 mg/L. The Covington sources are not chlorinated or fluoridated, but construction of a manganese removal filtration plant was recently completed for the Witte Road source.

The first and second round of tap water monitoring for the Covington Water District resulted in 90th percentile copper concentrations of 2.9 and 2.8 mg/L, respectively. These values were greater than the Lead and Copper Rule copper action level of 1.3 mg/L. The 90th percentile lead levels were below the lead action level for both sampling rounds. These results are similar to Auburn, where the 90th percentile lead levels were below the action level but the 90th percentile copper levels were greater than the action level.

A desktop evaluation was conducted for the Covington Water District in late 1993. The purpose of the study was to identify copper corrosion control strategies and rank them based on Covington's assessment priorities. Results of the studies ranked pH adjustment the highest, followed by corrosion inhibitors (i.e., orthophosphates and silicates).

A work plan was prepared for bench-scale testing of the recommended corrosion control treatment alternatives in early 1994. Laboratory testing was conducted by July 1994 using electrochemical methods. Fresh and aged copper pipe specimens were conditioned in the field prior to laboratory testing. Three treatment alternatives (pH adjustment, orthophosphates, and silicates) were tested using the copper pipe specimens and Covington water. Blends consisting of Covington water mixed with Auburn water and Cedar River water also were tested.

A summary of Covington's demonstration testing results is shown in Table 4-2. Loops A and B were conducted using Lake Sawyer water which exhibits a low pH similar to Auburn supplies. Loops C and D were conducted using Witte Road well water which has a slightly higher pH than the Lake Sawyer supply. Results indicate that pH adjustment and orthophosphate addition with pH adjustment at pH 7.7–7.8 were effective at reducing corrosion rates on copper surfaces. Silicates showed very little effectiveness for reducing corrosion rates. The recommended corrosion control strategy for Covington will likely be a modest pH increase to 7.5 - 8.0 and may be implemented in a phased approach.

pH and alkalinity levels exhibited by Auburn sources are similar to Covington's Lake Sawyer water quality. Bench-scale corrosion control testing results for

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Covington provide excellent analogous system information. These data indicate that pH adjustment between 7.8 and 8.2 would likely be an effective corrosion control treatment for Auburn. Results also indicate that phosphate addition at moderate pH (7.7–7.8) can be an effective copper corrosion control treatment for Auburn.

Table 4-2
Covington Water District
Bench-Scale Testing Summary of Results

Loop ID	Test Cycle Chemistry	Average Percent Change in Corrosion Rate on All Copper Surfaces	Average Percent Change in Corrosion Rate on Lead Surfaces
A	pH 7.8 to 8.2	-33	-45
	pH 8.2 to 9.0	-37	-56
B	pH 7.2 - 7.5, SiO_2 = 20 - 30 mg/L	-6	-11
	pH 7.2 - 7.4, PO_4 = 4 mg/L	-12	-22
C	pH 7.6 to 8.0	-14	-41
	pH 8.3 to 9.1	-41	-71
D	pH 7.4 - 7.9, SiO_2 = 20 - 30 mg/L	60	-4
	pH 7.7 - 7.8, PO_4 = 4 mg/L	-37	-30

Baseline pH for Loops A and B was 6.8 to 7.2; baseline pH for Loops C and D was 7.2 to 7.6.

4.2 City of Vancouver, Washington

The City of Vancouver, Washington serves water to over 108,000 people within its service area and is classified by the LCR as a large-sized system. Monitoring results for the first round of sampling indicate the 90th percentile lead level was 0.005 mg/L and the 90th percentile copper level was 1.4 mg/L, slightly above the copper action level. Vancouver is considered optimized for lead control due to the low lead levels found at the tap. The 90th percentile lead level for the second round was again 0.005 mg/L and the 90th percentile copper level was 1.2 mg/L, slightly below the copper action level.

The City is supplied by water from 8 water stations with a total of 17 wells. All stations provide chlorination and fluoridation. Additionally, Water Station 4 has been aerated for VOC removal since January 1992, and was modified in June and July 1992 after the first round of LCR monitoring was completed. After the second round of monitoring, aeration also was installed at Water Station 1 for VOC removal. As a result, approximately 50 percent of Vancouver's water supply is aerated. In addition to removing VOCs, aeration strips gaseous carbon dioxide from the water, raising the pH by as much as 1.0 unit from 6.5 - 7.0 to 7.5 - 8.0.

A third round of tap water monitoring for lead and copper was conducted in February 1994. Results indicated a very low lead level and a 90th percentile copper

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level of 1.26 mg/L, still below the copper action level. Table 4-3 indicates that those areas served with aerated well water showed significant decreases in median copper levels. The median copper level decreased from 0.92 mg/L in the first round to 0.14 mg/L in the third round, a significant decrease due to pH adjustment.

Table 4-3
City of Vancouver, Washington
Copper Concentrations for Monitoring at the Tap

Sampling Round	Percent Aerated	90th Percentile Copper (mg/L)	Median Copper Concentration (mg/L)
Round 1	0%	1.4	0.92
Round 2	20%	1.2	0.72
Round 3	50%	1.26	0.14

The dramatic decrease in copper levels at sites in Vancouver served by aerated water clearly shows the impact pH adjustment can have on copper levels at the tap for water with characteristics similar to Auburn. Finished water pH levels at Vancouver are approximately 8.0 for aerated supplies.

4.3 City of Renton, Washington

The City of Renton serves 43,000 people and is considered a medium-sized water utility in accordance with the Lead and Copper Rule. Renton drinking water is supplied by 8 wells and a spring. Five of the wells and the spring have very similar water quality, with low pH (6.3 to 6.5), moderate alkalinity (40 to 84 mg/L as $CaCO_3$), and high carbon dioxide concentrations (>20 mg/L). Treatment of the five wells and the spring consists of disinfection with free chlorine and fluoridation. Two new wells currently being brought on-line have very different water qualities, with pH levels closer to 8.0 and alkalinities around 100 mg/L as $CaCO_3$. Treatment for the new wells will consist of disinfection, fluoridation, sulfuric acid addition, inhibitor addition, aeration for hydrogen sulfide removal, and caustic soda addition. Iron and manganese levels are also higher in the new wells.

Lead and copper 90th percentile levels for both the first and second round met the lead action level, but exceeded the copper action level. The 90th percentile copper levels for the two rounds were 3.3 and 3.8 mg/L, respectively. Renton often receives customer complaints regarding blue-green staining, green tinted hair, and red water. The blue-green staining and green hair are indicative of a copper corrosion problem, while the red water, which seems to occur most frequently in areas with unlined cast iron pipe, indicate corrosion of the cast iron is occurring. As a result, Renton conducted a desktop corrosion control study which was completed in August 1993. Recommendations were made to conduct electrochemical corrosion testing to determine the optimum treatment for Renton's supply.

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Two treatment strategies, pH adjustment and orthophosphate addition, were tested in 1994 using Renton's existing supply. Tests were conducted using aged copper pipe, new copper pipe, and lead:tin solder dipped copper pipe. Results of the electrochemical testing indicate either pH adjustment to 7.7–8.6 or phosphate inhibitor addition at pH 7.5 would benefit Renton's corrosion control strategy for both lead and copper. The results of Renton's bench scale testing are summarized in Table 4-4.

Table 4-4
City of Renton, Washington
Bench-Scale Testing Summary of Results

Loop ID	Test Cycle Chemistry	Average Percent Change in Corrosion Rate on All Copper Surfaces	Average Percent Change in Corrosion Rate on Lead Surfaces
A	pH 6.5 - 6.8	+80	+210
	pH 7.7 - 8.1	-14	-14
	pH 8.3 - 8.6	-29	-17
B	PO_4 = 2 mg/L, pH 6.9 - 7.4	-30	-27
	PO_4 = 2 mg/L, pH 7.5 - 7.8	-56	-54
	PO_4 = 0.5 mg/L, pH 7.5 - 7.8	-28	-28
C	Orthopoly = 5 mg/L, pH 7.2–7.4	-39	-48
	Orthopoly = 2 mg/L, pH 7.1–7.3	-26	-44
	Ortho = 2 mg/L, pH 7.2–7.4	-42	-40

Baseline water was downtown well water at a pH between 6.9 and 7.4 with no phosphate addition.

As shown on Table 4-4, copper and solder corrosion surfaces in the Renton system are sensitive to both pH fluctuations and phosphate-based inhibitors. A pH increase alone would likely produce meaningful reductions in copper corrosion rates. A modest pH shift in combination with a moderate phosphate inhibitor dosage also could be used effectively to control copper corrosion based on demonstration testing results.

Water quality characteristics such as pH and alkalinity of Renton's downtown wells (Wells 1, 2, 3, 8, and 9) are similar to Auburn sources. A corrosion control strategy similar to Renton using either pH adjustment or phosphate addition at pH 7.5 likely would benefit Auburn. The recommended corrosion control strategy for Renton is likely to be a modest pH adjustment to 7.5–7.7 along with blended phosphate inhibitor addition for control of red water and iron and manganese precipitation, as well as copper corrosion control. Although phosphate addition may help control iron and manganese for certain Auburn wells (Well 3A and Well 3B) and red water concerns associated with unlined cast iron pipe, these concerns are low priority compared to copper release in the Auburn system.

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4.4 Seattle Water Department, Seattle, Washington

Seattle receives its water from the Cedar River and the South Fork Tolt River; both sources originate on the western slopes of the Cascade Mountains. These water sources generally are high quality with low hardness, low to neutral pH, low mineral content, and high dissolved oxygen concentrations. Source water from the Tolt River is considerably more corrosive than water from the Cedar River mainly due to significantly lower pH, alkalinity, and hardness levels. The number of corrosion related complaints increased substantially when the Tolt River supply came on line in 1964. The corrosion rates and corrosion related complaints again increased in 1970 when Seattle switched from chloramination to maintaining a free chlorine residual of at least 0.4 mg/L. Seattle began fluoridating with hydrofluosilicic acid at that time, which also contributed to increased corrosion by lowering pH levels and increasing the halogen:alkalinity ratio.

Prior to 1982 when corrosion treatment measures were implemented, the corrosiveness of Seattle's water was attributed to the following:

☐ Low pH of treated water (6.5 to 7.0 for the Cedar River and 5.5 to 6.0 for the Tolt River),

☐ High dissolved oxygen concentrations,

☐ Insufficient calcium and alkalinity to form $CaCO_3$ scale on pipe surfaces, and

☐ Relatively high halogen (chloride and fluoride) to alkalinity ratios resulting in conditions favorable to the pitting of iron piping.

In the fall of 1970, Seattle began a series of investigations into the corrosion problems caused by the water supply. These studies, which were conducted between 1970 and 1975, included: a literature search, tap sampling surveys, measurements of lead levels in blood, and coupon tests evaluating pipe corrosion rates. The effort focused on defining the nature of the corrosive tendencies and possible treatment alternatives. Three treatment alternatives (pH and alkalinity adjustment, pH adjustment and orthophosphate addition, and sodium silicate addition) were evaluated using weight loss measurements from pipe specimens. Exhibit 4-1 shows the corrosion rate penetration for copper pipe using Cedar River water. All three treatments show corrosion rates well below the control.

Based on several years of study, including the pilot plant pipe loop investigations, a corrosion control program was proposed. The corrosion control plan included: (1) a corrosion treatment program; and (2) selection of corrosion resistant materials for use in distribution and plumbing systems.

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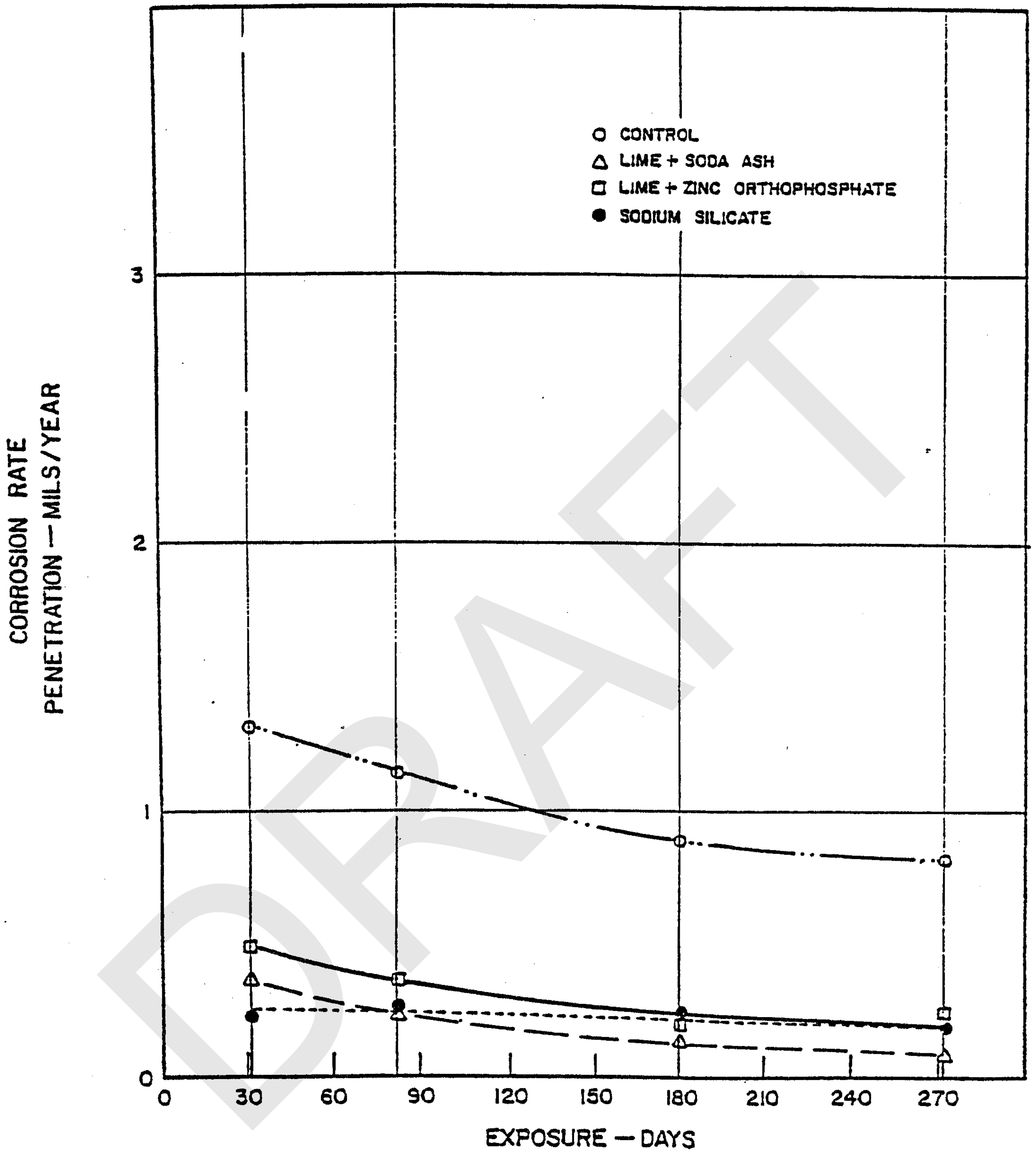

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Exhibit 4-1
City of Seattle
Cedar Chlorinated & Fluoridated Water
Copper Pipe Corrosion Rate vs. Time

The corrosion treatment program included increasing concentrations of minerals that were already present in the existing water supplies. The program proposed to raise the pH and alkalinity of the water and reduce the (halogen + sulfate) / alkalinity ratio. Silicate addition to the Tolt supply was also considered for further evaluation. The goal of the corrosion treatment program was to modify the characteristics of both water supplies to achieve a water quality that balanced corrosivity considerations with other water quality parameters, such as THM formation.

Corrosion treatment facilities were constructed on both water sources. The pH of the Cedar River supply was raised from 7.0 to 8.2 through the addition of approximately 2 to 5 mg/L of lime ($Ca(OH)_2$) at Lake Youngs. The pH and alkalinity for the Tolt River supply were raised to 8.2 and 13.5 mg/L as $CaCO_3$, respectively, by addition of 2 mg/L of lime and 9 mg/L of sodium carbonate (Na_2CO_3). Water treatment to reduce corrosion in Seattle's system has dramatically decreased metal concentrations as shown in Table 4.5.

Table 4-5
Seattle Water Department
Percent Reduction in Metal Concentrations in Standing Samples after Installation of Corrosion Treatment

Metal	Percent Reduction
Lead	65
Cadmium	59
Copper	64
Iron	29
Zinc	58

Monitoring of water quality, corrosion rates, and metal release before and after corrosion treatment has verified the success of Seattle's corrosion control program. Both metal release and corrosion rates have been significantly reduced by treatment. Aesthetic problems related to blue-green stains from copper corrosion have been eliminated and rusty water from iron pipe has been reduced.

Seattle Water Department's overall 90th percentile lead level from LCR monitoring was 0.019 mg/L, which exceeded the action level of 0.015 mg/L. However, closer examination of the results indicated that samples from the Tolt supply exceeded the action level during both rounds (90th percentile concentrations were 0.022 and 0.025 mg/L) and samples from the Cedar River supply did not exceed the lead AL (90th percentile concentrations were 0.0148 and 0.014). It is believed the 90th percentile levels for both the Tolt and Cedar service areas would have been much higher without the corrosion control measures already taken. Seattle Water Department's 90th percentile copper levels ranged from 0.30 to 0.54 mg/L and were well below the copper action level of 1.3 mg/L.

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Seattle has completed pipe loop tests using Tolt water to reduce corrosion on lead bearing materials in that system by creating water quality conditions similar to the Cedar River supply. Results of the pilot testing indicate that switching rechlorination stations located at open distribution reservoirs from gaseous chlorine to sodium hypochlorite will increase the pH of the water leaving the reservoirs and provide a corrosion benefit to direct service areas downstream of the reservoirs. Other Seattle Water Department system changes which will affect corrosion control include the following:

- ☐ Design and construction of the Tolt Filtration Plant;
- ☐ Feasibility studies and pilot work for ozonation facilities and possibly filtration facilities on the Cedar supply;
- ☐ Design and construction of the Tacoma intertie project; and
- ☐ Development of a plan to cover or reconfigure existing open distribution reservoirs.

Treated water for the Cedar supply exhibits an average pH of approximately 8.2 and alkalinity is near 22 mg/L as $CaCO_3$. The corrosion control treatment implemented for the Cedar and Tolt has resulted in low copper concentrations measured during LCR tap monitoring. Similar treatment by pH adjustment applied to Auburn's spring water supplies would likely result in a lowering of copper levels at customers' taps.

4.5 Bureau of Water Works, Portland, Oregon

The City of Portland and 20 wholesale customers throughout the Portland region who purchase water from the Bureau of Water Works conducted monitoring and are studying corrosion treatments. Portland exceeded the lead action level for both sampling rounds of the LCR and copper for the first round. The 90th percentile levels for the first round were 0.044 mg/L for lead and 1.8 mg/L for copper. The second round results were 0.053 mg/L for lead and 1.3 mg/L for copper.

The major water source for Portland is the Bull Run Watershed which originates on the western slopes of the Cascade Mountains. Due to steep topography and the nature of the soils, little opportunity exists for the water to naturally increase in mineral content. The source and treated (disinfected) water quality characteristics of Bull Run water which can cause it to be an aggressive water towards metal piping and fixtures the following:

- ☐ Acidic conditions as indicated by the chloraminated water's low pH values (6.5 to 7.2);

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☐ Low alkalinity (7 to 13 mg/L as $CaCO_3$) in the treated water;

☐ Low mineral content (hardness of 8 to 12 mg/L as $CaCO_3$) in the treated water;

☐ Low buffering capacity which offers little resistance to pH change with addition of acids or bases and can lead to localized low pH conditions; and

☐ High dissolved oxygen content (9 to 12 mg/L), essentially at saturation.

The Bureau has made considerable efforts over the past 10 years to evaluate the corrosivity of Bull Run water with respect to home plumbing and distribution piping. The Bureau has compiled a large water quality data base from which relevant corrosion-related information can be obtained. Additionally, it has conducted some preliminary evaluations of potential corrosion-control treatment alternatives.

The Bureau and 13 of its wholesale water customers are participating in a regional study as part of the requirements of the LCR. Because USEPA action levels for lead and copper were exceeded in the first monitoring period and because the Bureau is a large water utility according to the LCR, they embarked on a detailed Corrosion Control Study. In addition to desktop analyses, bench scale testing was conducted and results are summarized below.

A two-month evaluation of corrosion mitigation treatments using jar tests with water replacement, metals release, and electrochemical corrosion rate measurements was conducted. Nearly 25 treatments, modifying the quality of chloraminated Bull Run water, were evaluated. The main parameters influencing the corrosion rate, as well as the release of metals into the solution, were pH, alkalinity, and concentration of phosphate. Sodium silicate and a silicate/phosphate blend were also tested. Unchlorinated and free chlorine treated Bull Run water and distribution system waters were also tested, along with a groundwater source by itself, and blended with Bull Run water. The metal surfaces were exposed to the different water qualities for 40 - 45 days. The results provided useful data for selecting treatment alternatives for further pilot testing.

Conclusions of bench-scale testing included the following:

☐ pH increase to above 7.5 was beneficial in reducing copper and lead solder corrosion.

☐ Alkalinity increase to 15 mg/L was also highly beneficial; further benefit was realized by increases to 25 mg/L.

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- There was no indication that differences in corrosion protection were achieved between sodium hydroxide, lime, sodium bicarbonate, and carbon dioxide when used to reach equivalent pH and alkalinity values.

- Phosphate and zinc phosphate, when the pH and alkalinity were increased, were effective in reducing corrosion rates, especially lead release.

- Silicate and a silicate/phosphate inhibitor were effective in reducing copper corrosion and release, but less so for lead/tin solder.

- The groundwater was the least corrosive water tested. Its inhibiting effect was quite apparent when blended 50:50 with the chloraminated Bull Run water.

Portland continued to evaluate corrosion treatments through continuously flowing pipe loop test apparatus. The treatments evaluated included the following:

- Control - chloraminated Bull Run water
- pH adjustment to 8.0 and alkalinity adjustment to 25 mg/L
- pH adjustment to 9.0 and alkalinity adjustment to 20 mg/L
- pH adjustment to 7.5 and phosphate addition at 0.5 mg/L (as P)
- Sodium silicate addition at 10 mg/L (as SiO_2)

All four chemical treatment approaches reduced the release of lead and copper from lead solder, brass, and copper pipe into water compared to the current chloraminated Bull Run Water. The pH 9/alkalinity 20, the orthophosphate, and the silicate treatments performed effectively in reducing lead uptake from lead solder and brass, and copper uptake from copper pipe. The pH 8/alkalinity 25 treatment was consistently less effective than the other three treatments, but more effective than the control.

Exhibit 4-2 shows the relative copper levels from Portland's pipe loop testing using copper pipe. All four treatments were very effective at reducing copper concentrations compared to the control, including pH adjustment to 8.0 and alkalinity to 25 mg/L. Consideration of constraints and changes in water quality lead to the recommendation of pH 9/alkalinity 20 mg/L as $CaCO_3$ as the optimal corrosion control treatment approach for Portland.

Although Portland's alkalinity levels are lower than Auburn's spring sources, the pH levels are similar. Portland's LCR monitoring indicated corrosion of lead and copper is occurring under current water quality conditions, and corrosion control study results indicate pH adjustment, orthophosphate inhibitor addition, and silicates would be effective for reducing lead and copper levels at the tap.

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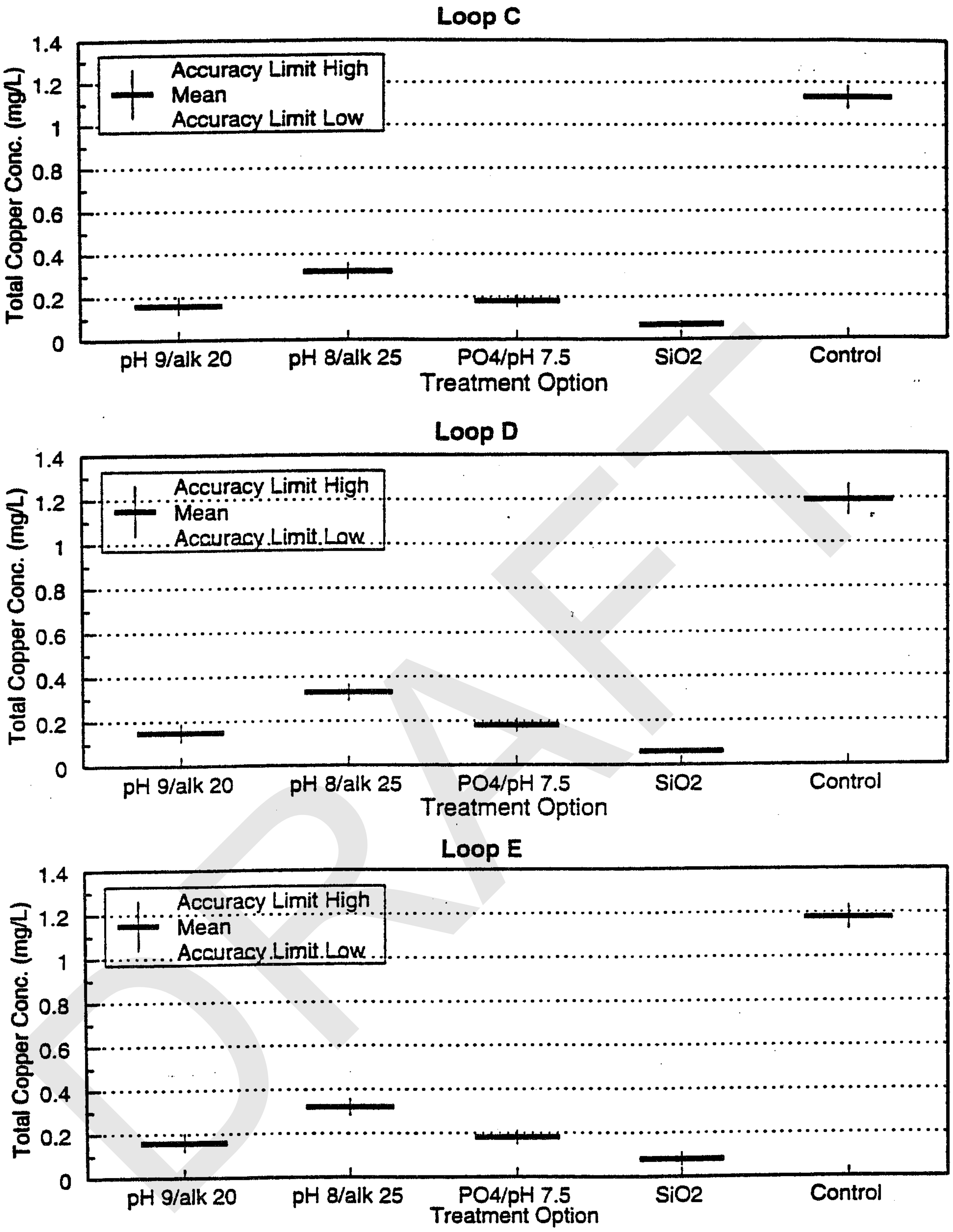

Copper levels in 1-L standing samples after uptake reate stabilization.
90% confidence within accuracy limits.

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Exhibit 4-2
Relative Copper Levels from Copper Pipe

Source: Portland LCR Corrosion Control Study, June 1994

4.6 Results of a WITAF Project

AWWA recently published a report sponsored by WITAF entitled *Initial Monitoring Experiences of Large Water Utilities Under USEPA's Lead and Copper Rule*. The project surveyed 660 large drinking water systems to collect information regarding the impact of the Lead and Copper Rule on their supply. Included in the information were first round lead and copper 90th percentile monitoring results, corrosion control effectiveness, and changes in operation due to the Lead and Copper Rule. Surveys were completed and returned for 60 percent of the utilities, representing 114 million people.

One section of the WITAF report focused on water quality and corrosion factors and their apparent influence on 90th percentile copper levels at the tap as reported by responding utilities. The term "percent action level (AL) exceedance" was used and indicates the percentage of utilities in a certain category that exceeded the 90th percentile action level of 1.3 mg/L for copper. Where possible, the data were divided into two categories before further analysis--water *without* an inhibitor (uninhibited) and waters *with* an inhibitor (inhibited). It should be noted that data in the WITAF report is not based on a rigorously controlled laboratory study, but are the results from the field efforts of hundreds of different utilities collecting samples at thousands of homes across the United States.

Distribution system pH levels showed an influence on the 90th percentile copper levels for utilities with and without corrosion inhibitors. Higher pH levels, i.e. greater than 7.5, have lower percent copper AL exceedances when compared with lower pH levels, i.e. less than 7.5. As indicated in Exhibits 4-3 and 4-4, the percent exceedances were 22.5 percent for uninhibited waters at pH <7.5, and were lower in higher pH ranges. Overall, higher pH levels were associated with lower percent AL exceedances for copper. Auburn's water supplies would fall in the lowest pH category (<7.5) where the largest percent exceeded the copper action level.

Exhibits 4-5 and 4-6 indicate some very interesting results relating to copper and alkalinity. It appears that the 90th percentile copper levels and the percent exceeding the AL are higher when alkalinity levels are below 25 mg/L as $CaCO_3$ and above 75 mg/L as $CaCO_3$ when corrosion inhibitors are not used. The window between 25 and 75 mg/L of alkalinity as $CaCO_3$ seems to be associated with lower 90th percentile copper levels. Auburn's spring water supplies exhibit alkalinity levels between 25 and 75 mg/L as $CaCO_3$ and Auburn's ground water supplies generally exhibit alkalinity levels in the range of 50 to 100 mg/L as $CaCO_3$.

Exhibits 4-7 and 4-8 present data related to pH, alkalinity, and percent copper AL exceedance levels. These data illustrate that water systems with pH levels ≤ 7.5 and alkalinity levels less than 25 mg/L as $CaCO_3$ or greater than 75 mg/L as $CaCO_3$ exceeded the copper action level more often than other systems included in the

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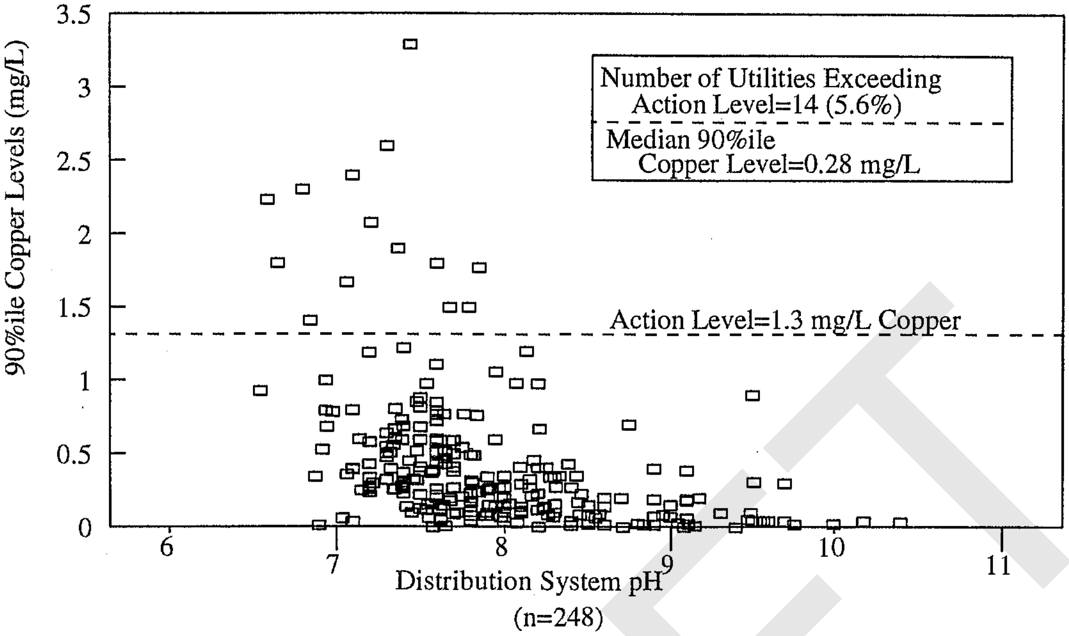
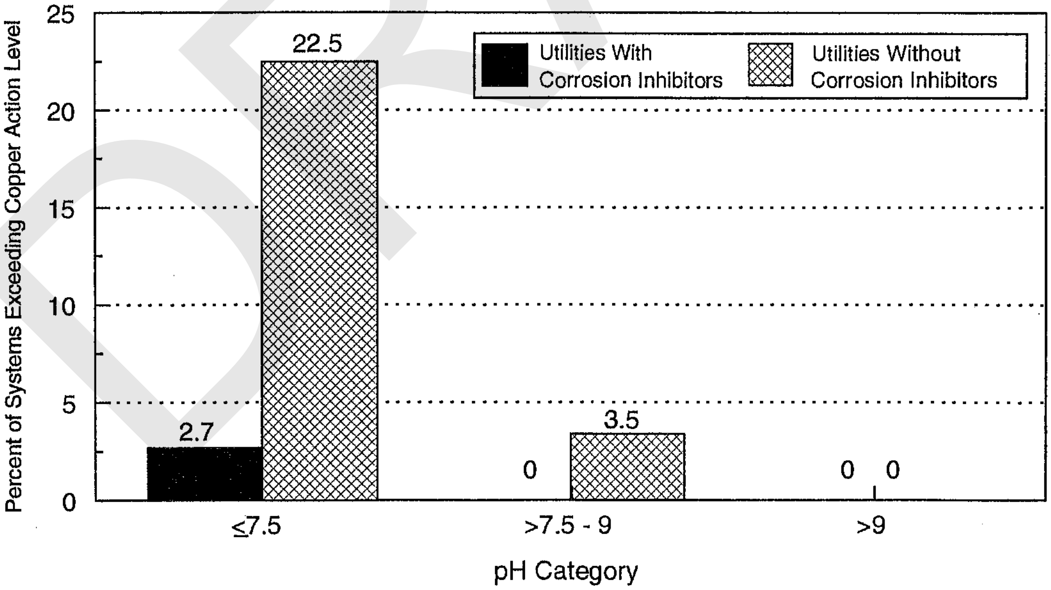


Note: Initial monitoring results of systems > 50,000 customers.

Exhibit 4-3

WITAF Survey Findings - Distribution System pH vs. 90th Percentile Copper Levels



Note: Initial monitoring results of systems > 50,000 customers.

Exhibit 4-4

WITAF Survey Findings - Copper AL Exceedances for pH Categories

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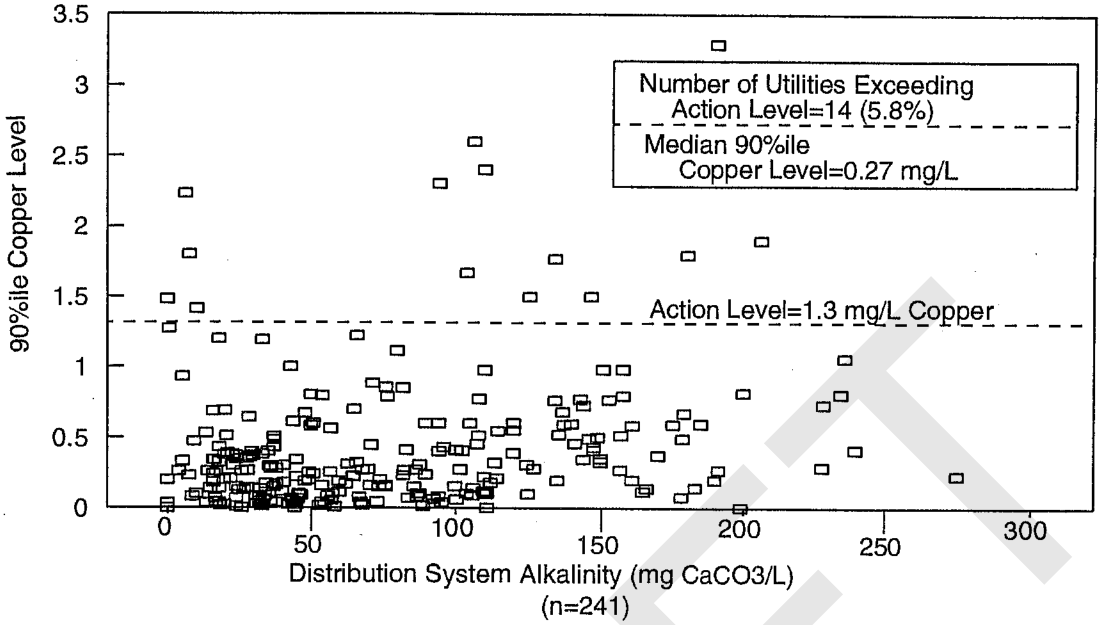
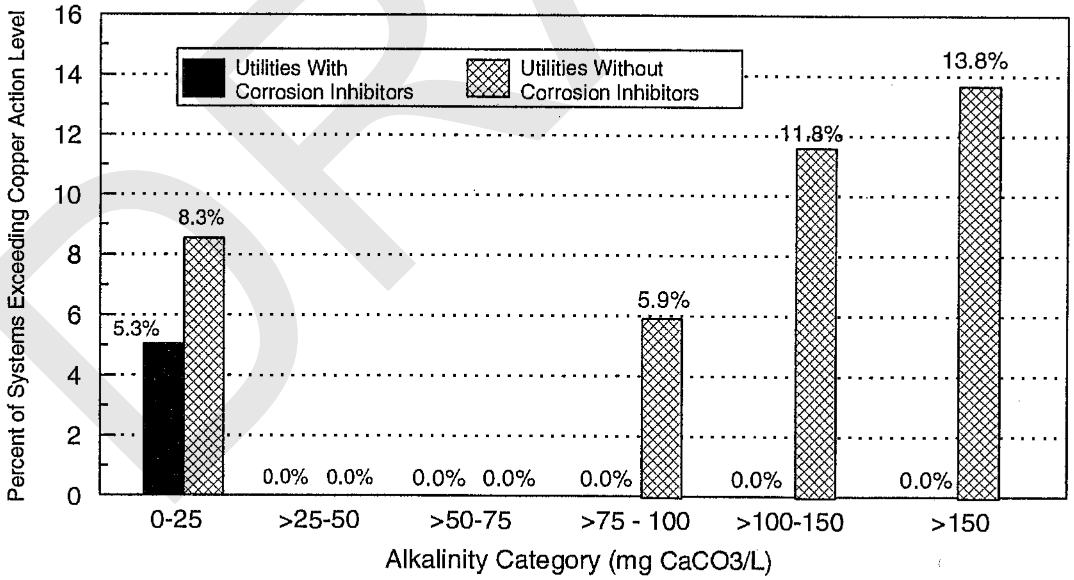


Note: Initial monitoring results of systems > 50,000 customers.

Exhibit 4-5

WITAF Survey Findings - Distribution System Alkalinity vs. 90th Percentile Copper Levels (all respondents)



Note: Initial monitoring results of systems > 50,000 customers.

Exhibit 4-6

WITAF Survey Findings - Copper AL Exceedence for Alkalinity Categories

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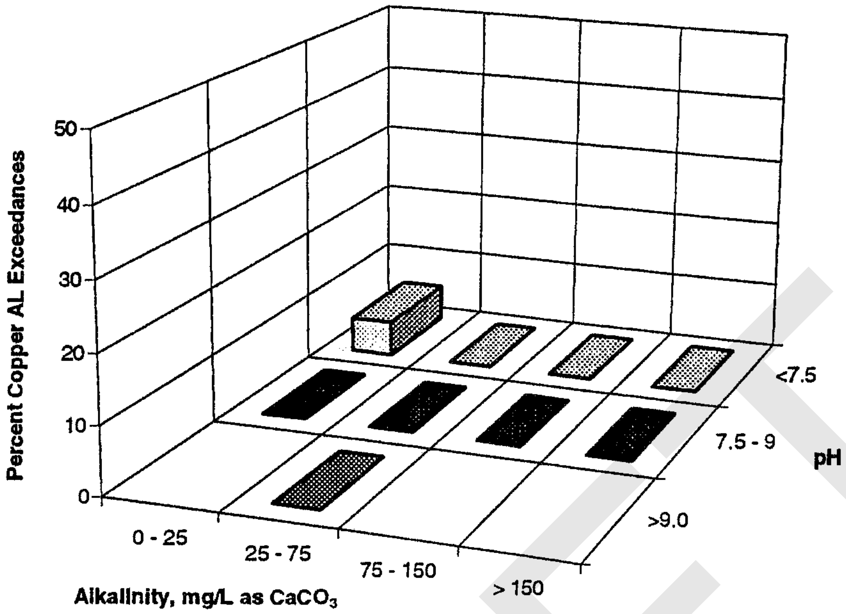

Exhibit 4-7
Exceedance of Copper Action Level as a Function of pH and Alkalinity, Inhibited Waters

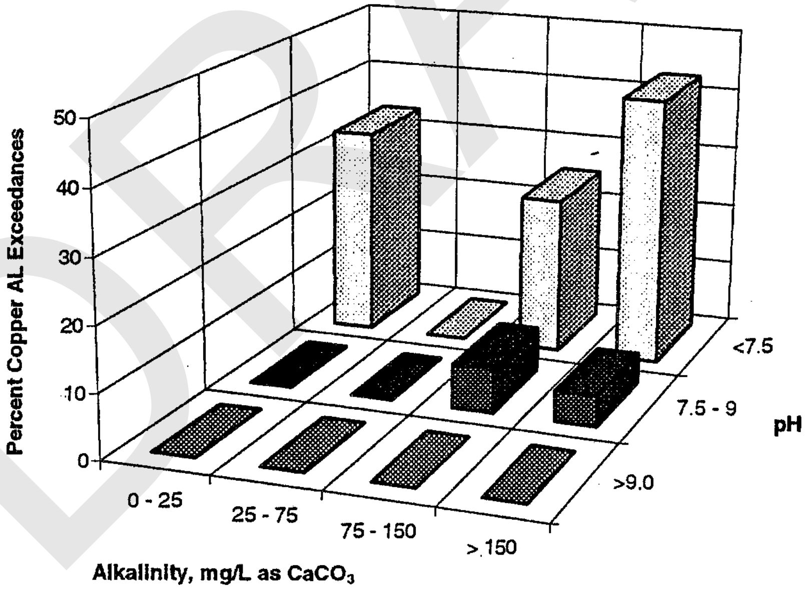

Exhibit 4-8
Percent of Copper Action Level Exceedances as a Function of pH and Alkalinity, Non-Inhibitor Waters

Source: WITAF Report *Initial Monitoring Experiences of Large Utilities Under USEPA's Lead and Copper Rule*
Utilities serving > 50,000

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survey results. Increasing pH levels regardless of the alkalinity level has a major beneficial effect of decreasing percent of copper AL exceedance. However, at the higher alkalinity levels, pH may need to be increased to a higher level to reduce copper release compared to lower alkalinity water. Auburn's water supply falls in the low pH, low–moderate alkalinity category, where none of the utilities exceeded the action level for copper.

The median 90th percentile copper levels for the 172 utilities without corrosion inhibitors was 0.28 mg/L compared to 0.27 mg/L for the 76 utilities using an inhibitor. However, only one respondent or 1.3 percent of the inhibited waters exceeded the copper AL compared with 7.6 percent of uninhibited waters. It is noteworthy that the one respondent with inhibited water that exceeded the copper AL reported a low pH between 6 and 7, and it is well documented that PO_4 is more effective when pH levels are in the mid 7s. Although there is no data to support this, there is speculation that some of those utilities currently using inhibitors could have exceeded the action level, had they not used the inhibitors. The use of an inhibitor is apparently associated with lower percent AL exceedances when compared with uninhibited waters. It also appears that inhibitors are effective in waters with the higher alkalinity levels where uninhibited waters experience trouble with copper AL exceedance. Table 4-6 provides a summary comparison between copper corrosion theory and WITAF survey findings.

Table 4-6
Comparison of Theoretical Aspects of Copper Corrosion with WITAF Survey Findings

Issue/ Question	Theoretical/ Historical Findings	Survey Findings	Comments
pH	Theory suggests a very strong relationship between pH levels and copper corrosion. Low pH levels (<6.0) are associated with increased corrosion and high pH levels (>8.0) with lower rates of corrosion.	Survey suggests a very strong relationship between pH and copper release. Low pH levels (<7.5) are associated with higher 90th percentiles and with larger percent AL exceedances. 7.5 < pH < 9.0 have lower 90th percentiles and much lower percent AL exceedances.	Theory and survey findings have excellent agreement. High pH levels will likely reduce the risk of copper AL exceedance.
Effect of Phosphate Inhibitor	Theory and some historical experience suggest that PO_4 would have a beneficial effect by reducing copper corrosion. Data is limited.	Survey findings seem to indicate that the presence of PO_4 has a positive effect by decreasing percent AL exceedances. Median 90th percentiles were nearly equal for inhibited and uninhibited waters, however inhibited water had lower percent copper AL exceedance.	Theory and survey findings seem to be in agreement, the presence of PO_4 appears to be beneficial for reducing copper AL exceedances.
Alkalinity	Little information on alkalinity and copper levels exist. Copper is strongly complexed by carbonate and carbonate containing species.	Survey suggests that alkalinity less than 25 mg/L and greater than 75 mg/L is associated with higher AL exceedances.	Interaction of pH and alkalinity is likely important. More research is needed.

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4.7 Conclusions

The following conclusions were developed regarding corrosion control treatment for Pacific Northwest ground water and surface water supplies and national WITAF survey results.

4.7.1 Ground Water Supplies

The spring and ground water supplies selected for comparison with Auburn were Covington, Renton, and Vancouver, Washington. Each of these systems exhibits water quality characteristics similar to Auburn supplies. All three systems conducted bench-scale or full-scale testing of corrosion control treatment alternatives and conclusions are summarized below.

☐ pH adjustment to 8.0 (with aeration) at Vancouver, Washington decreased the median copper level in full-scale testing from 0.92 to 0.14 mg/L.

☐ pH adjustment to 7.7–7.8 alone and orthophosphate addition at pH 7.2–7.4 were effective at reducing copper levels during Covington's bench-scale testing. Silicates were not effective for Covington water.

☐ pH adjustment above 7.7 alone and orthophosphate addition at pH 7.5 were effective at reducing copper levels during Renton's bench-scale testing.

4.7.2 Surface Water Supplies

Seattle and Portland have conducted full-scale or pilot-scale corrosion control testing for surface water sources. These sources exhibit pH values similar to Auburn (pH<7.5), but alkalinity values lower than Auburn. Results are summarized below.

☐ Seattle's Cedar and Tolt Rivers are currently treated with lime and soda ash (soda ash on Tolt only) to a final pH of 8.2 and alkalinity between 13 and 23 mg/L as $CaCO_3$. Corrosion control treatment has resulted in 90th percentile copper levels consistently below the copper action level.

☐ Portland's pilot testing found that pH/alkalinity adjustment above pH 8.0/alkalinity 20–25 mg/L was effective at reducing copper levels. Orthophosphate addition at pH 7.4 and silicates (which also increased pH) were effective for copper corrosion control.

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4.7.3 WITAF Survey Results

National WITAF survey results indicate that systems with pH levels greater than 7.5 reported 90th percentile copper concentrations which were below the copper action level more often than systems with a pH less than 7.5. No systems (regardless of alkalinity levels) exceeded the copper action level when the treated water pH was greater than 8.0.

Based on this review of analogous system data and information, pH adjustment and phosphate addition with pH adjustment to 7.5 appear to be viable corrosion control treatment alternatives that can be applied to the Auburn system. Data and information included in this section are used in Section 7 as a basis for the evaluation of viable treatment alternatives.

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Section 5
Regulatory and Functional Constraints

The U.S. Environmental Protection Agency (USEPA) Guidance Manual for the Lead and Copper Rule (LCR) requires that all constraints which may limit corrosion control treatment alternatives be identified. Any alteration of water quality through chemical addition will have some secondary impacts, which may conflict with proposed or existing regulations. Additional secondary impacts may arise which are not currently limited by Safe Drinking Water Act (SDWA) regulations.

This section evaluates potential regulatory and functional constraints which may limit the selection of a corrosion control treatment alternative for the Auburn water system (Auburn). A description of the three treatment alternatives which have been identified by the USEPA for corrosion control is included in Appendix B. Regulatory constraints are evaluated with respect to current federal and state drinking water quality requirements. Current and anticipated regulations which apply to the Auburn system were reviewed and the following regulations were determined to impact Auburn's selection of an optimal corrosion control treatment alternative:

☐ Surface Water Treatment Rule and Proposed Enhanced SWTR;
☐ Total Coliform Rule;
☐ Inorganic and Organic Chemicals;
☐ Trihalomethane Regulation;
☐ Proposed Radionuclides and Radon Rules;
☐ Proposed Disinfectant/Disinfection By-Products Rule;
☐ Draft Ground Water Disinfection Rule; and
☐ Future Regulation of Zinc.

Functional constraints were evaluated with respect to the impact of treatment alternatives on the Auburn system. Functional constraints which were considered include the following:

☐ Planning Considerations,
☐ Blending of multiple sources,
☐ Impacts on the community,
☐ Impacts on consecutive systems,
☐ Interference with existing treatment,
☐ Operations, and
☐ Specific water quality goals.

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5.1 Regulatory Constraints

The purpose of this assessment was to review all existing and proposed drinking water quality regulations that pose potential constraints to corrosion control treatment alternatives for the Auburn system. The approach taken in this assessment was to:

☐ Identify federal and state water quality regulations that are applicable to the corrosion treatment alternatives under consideration for Auburn's system;

☐ Identify those water quality characteristics that may change as a result of corrosion treatment processes; and

☐ Identify and summarize the potential constraints that these regulations may have on the corrosion treatment alternatives.

The following subsections provide a discussion of the impacts of Safe Drinking Water Act regulations on Auburn's selection of a corrosion control treatment. This subsection is divided into current SDWA regulations followed by anticipated regulations which are expected to impact the Auburn system. The most significant regulatory impacts are highlighted in the summary at the end of this subsection.

5.1.1 Current SDWA Regulations

Surface Water Treatment Rule

Possible constraints of the Surface Water Treatment Rule (SWTR) will apply to Auburn if either the Coal Creek springs or West Hill springs source is determined to be under the direct influence of surface water (GWUI). Auburn currently is evaluating the status of these sources by monitoring parameters such as turbidity, conductivity, and temperature. A final determination regarding the status of these sources will be made by the State in the future.

To meet the inactivation requirements of the SWTR, a disinfectant must be applied at a prescribed chlorine contact time (CT). CT is defined as the residual disinfectant concentration (C in mg/L) multiplied by disinfection contact time (T in minutes) prior to reaching the first customer. For free chlorine disinfection at constant temperature, the higher the pH of the water, the greater the required CT. Thus, if pH adjustment were employed by Auburn for corrosion control treatment, then the increase in water pH would require a higher chlorine dose and/or longer contact time to meet the CT requirement of this rule.

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If the SWTR requirements for groundwater under the influence of surface water must be met by Auburn for any of its sources, then Auburn's selection of a corrosion control treatment option may be constrained by requirements to meet a prescribed CT prior to the first customer. If applicable to Auburn, the Enhanced SWTR would increase CT requirements for primary disinfection.

Total Coliform Rule

The Total Coliform Rule set standards for the microbiological quality of water in the distribution system. It set MCLs for total coliforms using the presence/absence approach in routine monthly samples from the distribution system and source waters based on system population. Auburn monitors for coliforms according to a written coliform monitoring plan and meets the requirements of this rule.

Auburn's selection of a corrosion control treatment alternative may be constrained by this rule. By increasing the pH for corrosion control treatment, Auburn potentially could encounter lower disinfection efficiency, higher heterotrophic plate counts (HPCs), or presence of total coliforms. To compensate, Auburn may be required to increase chlorine residuals to control coliforms and HPCs.

The addition of phosphate-based corrosion inhibitor chemicals may add an additional nutrient source to the finished water, which may stimulate HPC bacteria and/or algal growth in water systems with open reservoirs. However, many utilities without open reservoirs successfully use phosphate inhibitors for corrosion and scale control without bacterial regrowth problems. Since Auburn has no open distribution reservoirs, this issue is not considered to be a critical constraint for Auburn's selection of optimal corrosion control treatment.

Inorganic and Organic Chemicals

From the lists of inorganic and organic chemicals included in the Phase II and Phase V Rules, only cadmium and antimony are related to corrosion control and considered potential regulatory concerns. Because regulatory compliance for cadmium and antimony is based on samples taken at distribution system entry points rather than customers' taps, it is unlikely that the Phase II and Phase V SOC/IOC Rules will pose constraints on Auburn regarding the selection of optimal corrosion control treatment. The uptake of these metals may occur in the distribution system under similar water quality conditions that promote lead and copper uptake. The extent that cadmium and antimony uptake occurs in the Auburn system would need to be confirmed by testing.

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Trihalomethane Regulation

In the State of Washington, the MCL for total THMs (TTHM) is 100 μg/L. This regulation applies to all surface water and ground water systems which disinfect with chlorine and serve a population of 10,000 or more. Surface water systems must monitor for TTHMs and ground water systems must monitor for maximum trihalomethane formation potential (MTTP).

Selected TTHM and MTTP results reported for Auburn sources since 1988 are summarized on Tables 5-1 and 5-2. TTHM results are shown for the Coal Creek and West Hill springs, which are disinfected with free chlorine continuously. These results show that TTHM levels were consistently less than the MCL of 100 μg/L.

Table 5-1
Auburn Water System
Selected Total Trihalomethane Results (μg/L)

Date	Coal Creek Springs	West Hill Springs
1988	3.4	8.8
1989	5.7	3.5
1992	3.2	—
1993	3.2	5.6

MTTP results are shown for Well #1, Well #3A, Well #3B, Coal Creek and West Hill springs. These data indicate the highest value for MTTP was 32.1 μg/L for the Coal Creek springs sample which was collected in 1991.

Table 5-2
Auburn Water System
Maximum Total Trihalomethane Potential Results (μg/L)

Date	Well #1	Well #3A	Well #3B	Coal Creek Springs	West Hill Springs
1991	—	—	—	32.1	—
1992	18.2	—	—	17.3	—
1993	20.3[1]	18[2]	15[3]	15[4]	18.4[5]

1 Sample collected in the distributions system at 32721 111 Place S.E.
2 Sample collected at 1913 37th Street S.E.
3 Sample collected in the distributions system at 725 28th Street S.E.
4 Sample collected in the distribution system at 10802 293rd Street.
5 Sample collected in the distributions system at 212 Hi Crest Drive.

It is well established that the potential for THM formation increases with elevated pH. Raising the pH for corrosion control likely would increase THM or MTTP concentrations. Based on mathematical modeling of the formation of TTHMs in chlorinated natural water (AWWA-WITAF, 1993), Auburn is not expected to observe an increase in TTHM levels beyond the MCL of 100 μg/L if the pH is increased to 8.0 for corrosion control treatment.

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5.1.2 Anticipated Regulations and Other Considerations

Safe Drinking Water Act regulations which are expected to impact the Auburn water system in the future include the anticipated Radionuclides Rule, Radon Rule, Disinfectant and Disinfection By-Products Rule, and the Ground Water Disinfection Rule. Other water quality parameters which may be a concern to Auburn include zinc, iron and manganese. Possible constraints imposed on the Auburn system by these anticipated regulations and water quality concerns on the selection of optimal corrosion control treatment are discussed below.

Radionuclides and Radon Rules

The federal Radionuclides Rule was proposed on July 18, 1991 and it included an MCL of 300 pCi/L for radon. The USEPA plans to finalize a rule in April 1995 that will set standards for the non-radon contaminants in the Radionuclides Rule. The MCL for radon has not yet been decided, but recent developments indicate that the final MCL may be within the range of 200 to 1,000 pCi/L.

Samples were collected from Auburn sources and analyzed for radon in August 1994 (Table 5-3). No radon data are available for the West Hill springs or Hidden Valley sources. Samples collected from Auburn sources which serve the Valley, Lea Hill, and Academy pressure zones (Coal Creek springs, Well 1, Well 2, Well 3A, Well 3B, and Well 4) exhibit radon levels ranging from 205 to 285 pCi/L. Results obtained from Auburn sources which serve the Lakeland Hills pressure zone (Well 5 and Well 5A) exhibit radon levels ranging from 710 to 825 pCi/L.

Table 5-3
Auburn Water System
Radon Concentrations for Selected Sources[1]

Source Name	DOH ID #	Radon-222 (pCi/L)
Coal Creek Springs	S01	285
West Hill Springs	S02	–
Well 1	S03	215
Well 2	S04	270
Well 3A	S05	205
Well 3B	S08	225
Well 4	S06	240
Well 5	S07	710
Well 5A	S09	825
Hidden Valley[2]	S01	-

[1] *Samples collected in August 1994.*

[2] *Hidden Valley is a satellite system which is operated by the City of Auburn, but it is not connected to the Auburn distribution system.*

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If the MCL for radon is set at 200 pCi/L at the source, then Auburn may be required to treat all of its sources. However, if the MCL for radon is set at 300 pCi/L at the source, then Auburn may be required to treat only Well 5 and Well 5A prior to discharge to the Lakeland Hills pressure zone. Best available technology for radon removal includes aeration, adsorption, synthetic resin adsorption, and activated carbon.

The selection of optimal corrosion control treatment for the Auburn system should address the possibility of radon removal to meet the anticipated requirements of the Radon Rule. For example, if pH adjustment is selected as the preferred corrosion control treatment method, then aeration technology may be suitable for removing radon and reducing the corrosive tendency of Auburn sources in the distribution system. Blending of Auburn sources also may serve to reduce radon levels in the distribution system. Since the Radon Rule is still being developed, the timing of the new rule is uncertain.

Disinfectant and Disinfection By-Products Rule

The USEPA proposed the Disinfectant and Disinfection By-Products (D/DBP) Rule on July 29, 1994. The proposed D/DBP rule focuses on surface water and ground water sources with high levels of total organic carbon (TOC) and exhibit the potential for forming DBPs. The new rule likely will be implemented in two stages. The first stage is expected to become effective in the year 2000 for ground water systems serving more than 10,000 people. The second stage of the rule will be developed by regulatory negotiation or a similar consensus process beginning in 1998.

For the first stage of the D/DBP rule, MCLs likely will be set at 80 μg/L for total trihalomethanes and 60 μg/L for haloacetic acids. The second stage of the rule is expected to reduce the MCLs to 40 μg/L for total trihalomethanes and 30 μg/L for haloacetic acids. The maximum residual disinfectant level for chlorine is likely to be 4.0 mg/L (as Cl_2) measured in the distribution system. Other requirements also will be specified for monitoring ground water systems.

Assuming all other factors remain unchanged, an increase in pH generally results in an increase in total THMs and a decrease in total HAAs. As discussed previously, TTHM levels exhibited by Auburn sources are low and they are not expected to be increased significantly by elevated pH. No HAA data are available for Auburn sources, but modeling results (AWWA, 1993) indicate that the potential formation of HAAs is not expected to be a concern.

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The disinfectant concentration limit of 4 mg/L set by the proposed D/DBP rule is not expected to impact Auburn because Auburn does not typically use high levels of chlorine residual in its system. Corrosion control treatment alternatives which are being considered for the Auburn system likely will not require chlorine residuals in excess of 4 mg/L.

Ground Water Disinfection Rule

The amended Safe Drinking Water Act requires the USEPA to establish disinfection requirements for all public water systems. To date, disinfection requirements have been established for surface water and ground water under the direct influence of a surface water per the SWTR. A regulation known as the Ground Water Disinfection Rule (GWDR) currently is being developed for ground water sources. According to the draft rule released on July 31, 1992, ground water systems will would be required to maintain continuous disinfection of water entering the distribution system and maintain a detectable disinfectant residual (or HPC <500/mL) in the distribution system (unless wells meet "natural disinfection" criteria as defined by the rule).

The GWDR is expected to establish a primary disinfection requirement for the inactivation of viruses, but the magnitude of the ground water CT requirements are expected to be less than the current CT requirements of the SWTR. As discussed previously, an increase in pH for corrosion control may decrease the disinfection efficiency of chlorine. As a result, higher dosages (or longer contact time prior to the first customer) may be required to meet the conditions of the GWDR.

Auburn currently chlorinates its Coal Creek and West Hill spring sources, which provide approximately 50 percent of the total system supply and serve the Valley, Lea Hill, and Academy pressure zones. If DOH determines that these spring sources are not subject to the requirements of the SWTR (as GWUI), then Auburn still may be required to construct new facilities or implement system modifications to achieve primary disinfection requirements for its springs and wells per the GWDR.

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Zinc

The National Sanitation Foundation (NSF) is a non-commercial agency that develops standards and criteria for equipment, products, and services that affect human health. In 1988, the NSF (in association with the AWWA Research Foundation, the Association of State Drinking Water Administrators, the AWWA, and the USEPA) established the maximum drinking water level (MDWL) for zinc at 2.0 mg/L. This MDWL is less than the Washington State secondary MCL for zinc (5 mg/L) and it could limit the concentration of zinc applied to the Auburn system, if Auburn selects an inhibitor such as zinc orthophosphate as the optimal corrosion control treatment for its system.

Iron and Manganese

In the State of Washington, secondary MCLs are 0.3 mg/L for iron and 0.05 mg/L for manganese. For the Auburn system, water produced from Well 3A and Well 3B typically exhibit high levels of iron and manganese which are greater than the secondary MCLs. These wells typically are used only during peak demand periods. If a pH increase is selected as the optimal corrosion control treatment for the Auburn system, then precipitation of iron and manganese may be exacerbated in the distribution system. Alternatively, if an inhibitor (such as polyphosphates) is selected for corrosion control treatment, then the potential for red or black water may be reduced by sequestering iron and manganese. These possible effects of corrosion control treatment alternatives on Auburn water containing high levels of iron and manganese (Wells 3A and 3B) should be tested in the laboratory prior to implementation in the system.

5.1.3 Summary of Potential Regulatory Constraints

A summary of potential regulatory constraints that may impact Auburn's selection of an optimal corrosion control treatment is presented on Table 5-4. The purpose of Table 5-4 is to summarize water quality parameters that may change as a result of using a corrosion control treatment approach and to identify areas of Auburn's regulatory compliance status that may be impaired by selecting a specific treatment approach. The three corrosion control treatment alternatives which are under consideration for Auburn's system included the following:

- ☐ pH adjustment;
- ☐ Inhibitor addition; and
- ☐ Calcium carbonate adjustment.

The three corrosion control treatment alternatives are not constrained by existing and future regulations to such an extent that any one treatment alternative should be eliminated. However, if the selected corrosion control treatment includes pH elevation, then the treatment may be constrained to a limited extent for the following reasons:

- ☐ An increase in pH would require a greater free chlorine CT to meet the SWTR if either the Coal Creek or West Hill springs are determined to be under the influence of surface water. This phenomena also may be a concern for meeting future CT requirements of the anticipated

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Table 5-4
Summary of Potential Regulatory Constraints and Impacts on Selection of a Corrosion Control Treatment

Corrosion Control Treatment Approach	Water Quality Parameters That May Change	SWTR (GWUI)/GWDR	Total Coliform Rule	Existing THM Regulation and Future D/DBP Rule	Radon and Phase II-VOCs
pH Increase	pH, Metals, Chlorine, Coliform, HPCs, THMs	*pH elevation would require higher Ct for equivalent level of chlorine disinfection.	*pH increase may lower disinfection efficiency and require higher chlorine residuals to control coliforms and HPCs.	pH increase generally results in THM level increase. Possible elevation of chlorine residuals may result in increases of other chlorinated by-products.	* Aeration would likely decrease radon and VOC levels.
Phosphate Inhibitor Addition	Phosphorus, Metals				
Silicate Inhibitor Addition	Silicate plus parameters listed under pH increase since silicate addition can result in a pH increase up to 2 pH units	Higher silicate levels can form precipitates, resulting in turbidity increase. * Also, same constraints as pH increase.	* Same as pH increase	Same as pH increase	
Calcium Carbonate Adjustment	Turbidity, others similar to pH increase	Lime addition may result in slight turbidity increases, * Also, same constraints as pH increase.	* Same as pH increase	Same as pH increase	

* *Indicates a constraint of greater concern based on potential risk to health and/or cost to the Auburn system.*

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GWDR. However, the magnitude of the CT requirements for the GWDR is expected to be less than the current CT requirements of the SWTR.

☐ An increase in pH may lower the disinfection efficiency of chlorine. This phenomena may result in higher chlorine residuals required to control coliforms and HPCs in the distribution system.

☐ Compliance with future THM and other chlorinated by-product MCLs may limit the upper range of pH increases, and possibly may limit chlorine dosages.

☐ pH adjustment using aeration may benefit Auburn by removing radon from certain sources (e.g., Well 5 and Well 5A). If pH adjustment is selected by Auburn as the optimal corrosion control treatment, then additional study should be conducted to evaluate the impact of aeration on radon removal.

5.2 Functional Constraints

Functional constraints which potentially could impact Auburn's implementation of corrosion control treatment alternatives are identified below. Functional constraints include planning considerations, blending of multiple sources, impacts on the community, impacts on consecutive systems, interference with existing treatment, operational constraints, and specific water quality goals. A summary of the major functional constraints identified for the Auburn system are summarized at the end of this section.

5.2.1 Planning Considerations

The City of Auburn currently is planning to develop new ground water sources (Wells 6 and 7). If the quality of water produced by the new wells is similar to the quality of water from existing Auburn sources, then the blending of water from these wells is not expected to impact significantly Auburn's selection of corrosion control treatment. However, the production capacity and area which will be served by these new wells may influence the design and implementation of corrosion control treatment.

A new pump station currently is being considered by Auburn to increase pumping capacity from the Valley to Lea Hill pressure zones. The new pump station may be required to meet new demands associated with future interties with Water District 111 and Covington. The new pump station may be equipped with a booster chlorine feed system and it may provide a location for corrosion control treatment.

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5.2.2 Blending of Multiple Sources

The process of blending different water supplies can create water quality concerns for a purveyor, even when each supply meets all drinking water standards. Blending can affect the physical, chemical, microbiological, and radionuclear characteristics of water in the bulk phase as well as equilibrium at the water-pipe interface. In the bulk phase, water quality characteristics such as pH, chlorine residual, dissolved oxygen, turbidity, disinfection by-products, fluoride levels, mineral content, and radionuclides levels can be affected by blending two or more supplies.

At the water-pipe interface, re-equilibration can affect the interior lining of transmission, storage, and distribution facilities when one or more supplies are blended together. Re-equilibration issues may include internal corrosion, solubilization of iron scales, regrowth of microorganisms, and resuspension of sediment. Re-equilibration at the water-pipe interface may be attributed to changes in water chemistry (e.g., dissolved oxygen).

Auburn currently produces water from two springs and seven ground water sources. Water from the springs are disinfected with chlorine and blended with untreated well water in the distribution system. Specific water quality concerns associated with blending Auburn spring water and well water are discussed below.

Blending Auburn Spring Water and Well Water

Water from Coal Creek and West Hill springs are disinfected with chlorine and blended with water from Wells 1, 2, and 4 in the Valley and Lea Hill pressure zones. During peak demand periods, Wells 3A and 3B also are used and discharged to the Valley and Lea Hill pressure zones. As discussed previously, the Auburn sources exhibit similar water quality characteristics as related to lead and copper corrosion (low pH, low-moderate alkalinity and low-moderate calcium concentration). Other parameters that may affect water quality after blending include dissolved oxygen, iron, manganese, and radon. These water quality parameters are summarized on Table 5-5.

Data collected in September 1994 indicate that dissolved oxygen levels for Coal Creek and West Hill springs range from 8.5 to 9.6 mg/L. Data also indicate that dissolved oxygen level for well water ranges from 2.2 to 6.0 mg/L. These dissolved oxygen levels appear to be high since the oxygen content of ground water at depths greater than 100 to 150 feet generally is considered to contain little or no dissolved oxygen (Driscoll, 1989; U. S. G. S., 1992). These high levels of dissolved oxygen may be attributed to exposure to the atmosphere during sample collection and handling.

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Table 5-5
Auburn Water System
Selected Water Quality Parameters for Auburn Sources

Source Name	DOH Source ID #	Dissolved Oxygen (mg/L)[a]	Iron (mg/L)[b]	Manganese (mg/L)[b]	Radon-222 (pCi/L)[c]
Coal Creek Springs	S01	8.5	<0.03 - 0.04	<0.01	285
West Hill Springs	S02	9.6	<0.03 - 0.10	<0.01	-
Well 1	S03	3.3	<0.03 - 0.08	<0.01 - 0.015	215
Well 2	S04	2.2	<0.03 - 0.24	<0.01	270
Well 3A	S05	2.5	0.24 - 1.22	0.112 - 0.179	205
Well 3B	S08	3.2	<0.03 - 0.16	0.360 - 0.463	225
Well 4	S06	3.4	<0.03 - 0.46	<0.01	240
Well 5	S07	6.0	<0.03 - 0.12	<0.01	710
Well 5A	S09	3.7	<0.03	<0.01	825
Hidden Valley[d]	S01	-	0.05	<0.01	-

a *Based on samples collected on September 26, 1994.*
b *Based on samples collected from 1987 to 1994.*
c *Based on samples collected in August 1994.*
d *Hidden Valley is a satellite system which is operated by the City of Auburn, but it is not connected to the Auburn distribution system.*

The dissolved oxygen data included in Table 5-5 may be used as a qualitative indication of the relative level of dissolved oxygen in water from Auburn springs and well sources. Higher dissolved oxygen levels are not a concern for the Auburn system, which is accustomed to the quality of water from the Auburn spring sources. However, the higher dissolved oxygen levels in the Auburn spring water may be a concern for consecutive systems as discussed below. A more rigorous sampling and handling protocol (see *Standard Methods*, 1992) would need to be conducted to obtain dissolved oxygen concentrations which are representative of the Auburn sources.

The data on Table 5-5 indicate elevated levels of iron and manganese for Wells 3A and 3B compared to the other Auburn sources. As discussed previously, Wells 3A and 3B only are used during peak demand periods and customers are notified in advance regarding the use of these wells. Data on Table 5-5 also indicate elevated levels of radon for Wells 5 and 5A. These wells only serve the Lakeland Hills pressure zone and the water does not mix with water served to the Valley and Lea Hill pressure zones. Any changes in current operations could potentially affect the quality of water served to these customers.

5.2.3 Impacts on the Community

Changes in water quality resulting from corrosion control treatment potentially can impact water users including industrial and commercial

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users, wastewater treatment facilities, wholesale customers, and the general public. During September 1994, Auburn sent surveys to 37 water users and 11 plumbing shops regarding possible impacts of corrosion control treatment alternatives on their operations. Surveys were sent to water users connected by a 3-inch or larger service line. Auburn received responses from seven water users and one plumbing shop (Appendix C). The contents of these responses are summarized on Table 5-6.

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Table 5-6
Auburn Water System
Summary of Responses to Survey Regarding Impacts of Corrosion Treatment on Customers' Water Quality

Name of Respondent	Type of Business	Water Use	Water Quality Concerns
Auburn School District	Domestic	Domestic water supply; Heating and cooling	ΔpH - small increase in boiler chemicals; ΔZn - no adverse impact; ΔPO_4 - no adverse impact; ΔSi - possible increase in pump wear.
Childhaven	Domestic	Domestic water supply	ΔpH - no, as long as it is safe; ΔZn - no adverse impact; ΔPO_4 - no adverse impact; ΔSi - no adverse impact.
King County Housing Authority	Domestic	Domestic water supply	Respondent did not understand the questions.
Rio Verde Mobile Estates	Domestic	Domestic water supply; Landscape irrigation; Swimming pool.	ΔpH - no adverse impact; No response to other questions
The River Mobile Estates	Domestic	90% domestic; 10% irrigation	Respondent did not understand the questions.
Supervalu West Coast Grocery Division	Industrial and Commercial	Refrigeration cooling towers	ΔpH - would require adjustment of cooling water treatment; ΔZn - no adverse impact; ΔPO_4 - no adverse impact; ΔSi - yes, would cause buildup of scale in cooling towers.
Auburn General Hospital	Health Care	Domestic water supply; Heating and cooling; Medical sterilization.	ΔpH - none known; ΔZn - do not know; ΔPO_4 - do not know; ΔSi - hard on boilers.

ΔpH *Response to survey questions regarding possible impacts of a change in pH from 6.8 to 7.5 or from 6.8 to 8.0 in Auburn water.*

ΔZn *Response to survey question regarding possible impacts of an increase of 0.5 mg/L of zinc in Auburn water.*

ΔPO_4 *Response to survey question regarding possible impacts of an increase of 0.5-2 mg/L of orthophosphate in Auburn water.*

ΔSi *Response to survey question regarding possible impacts of an increase of 5-10 mg/L of silica in Auburn water.*

Domestic Users and the General Public

Respondents to the survey who are domestic water users generally expressed a concern for overall water safety. Two respondents did not understand the questions. Some domestic water users with large-scale heating and cooling systems are concerned with the possible impact of a change in pH on their specific chemical treatments and the possible adverse effect of silica on their system.

In 1994, the City of Portland, Oregon conducted a survey of industrial, commercial, and institutional customers regarding the impact of corrosion control treatment on water quality using pH adjustment or inhibitors. The City of Portland concluded the following:

☐ The use of sodium-based chemicals (e.g., caustic soda) for corrosion control would not present a concern for increased scaling in boilers or cooling towers. However, an increase in pH above approximately pH 8.0 could result in a need for increased use of biocide or change in the type of biocide used.

☐ The use of silicates for corrosion control would result in a higher increase in the blowdown rate for boilers and bleed rate for open recirculating cooling systems to prevent the formation of scales. This could result in increased water and chemical costs.

☐ Facilities requiring high purity water (e.g., microelectronics manufacturing plants, medical clinics, pharmaceutical manufacturing plants, and research and testing laboratories) objected to the use of silicates more than other proposed corrosion control treatments because these facilities would need to remove the added silica from their water.

As discussed previously, customer inquiries regarding blue/green staining typically occur for new homes. The fact that Auburn exceeded the copper action level also indicates that corrosion of household plumbing is occurring and impacts water quality at the tap. Corrosion control treatment should minimize the aggressiveness of Auburn's water to household plumbing material.

Implementation of corrosion control treatment could have economic and health impacts on Auburn water users. The life of customers plumbing will be extended, which could generate positive economic results for Auburn customers. Health-related issues (such as increased sodium levels) and the possible negative perception regarding the addition of chemicals to drinking water may need to be addressed by Auburn. The intent of the Lead and

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Copper Rule is that real or perceived health risks associated with water treatment will be offset by decreasing the concentration of soluble metals in customers' drinking water. If desired by Auburn, health, aesthetic, and economic concerns of the general public can be addressed through active public education/involvement programs prior to installation of any treatment alternative.

Industrial, Commercial, and Health Care Facilities

Typically, industrial users and commercial facilities with specialized water needs can be susceptible to the addition of chemicals such as phosphates or silicates to the water supply, requiring an alteration in their water treatment process. Health care facilities also should be advised regarding any changes in water quality. Respondents to Auburn's water treatment survey who represent commercial and health care facilities indicate concerns which are similar to the concerns expressed by large-scale domestic users. Specifically, the water quality concerns pertain to the potential effects of pH adjustment on their water treatment chemicals and the potential effects of silica on their system. If any additional responses to this survey are received by Auburn, then their comments will be included in the final desktop report.

Wastewater Treatment Facilities

Wastewater generated by the Auburn service area is treated at the Metro wastewater treatment plant in Renton. According to representatives of Metro (Metro, 1994a; 1994b), the pH range which is allowed by the NPDES permit for discharge from the Renton wastewater treatment plant is 6.8 to 9.0. The Renton permit limits are 0.11 mg/L for copper and 0.05 mg/L for zinc. Although phosphorus concentration currently is not limited for the Renton plant, Metro staff would prefer to minimize phosphorus loading in the event that phosphorus limits are imposed on Renton in the future. Metro representatives expressed a preference for pH adjustments compared to the other two treatment alternatives (inhibitors or calcium adjustment).

5.2.4 Impacts on Consecutive Systems

For the purpose of this desktop evaluation, consecutive systems are defined as systems that purchase water from Auburn for continuous supplies, peak demand and/or emergency service. Auburn currently is negotiating plans to provide water to Water District 111 and Covington Water District on a continuous basis via the Lea Hill pressure zone. In addition, Auburn is considering a possible sale of 2.0 MGD of water to Lakehaven Utility District. Auburn also provides peak water demand to Algona during the summer and emergency service to Kent and Pacific. Specific water quality concerns

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associated with possible blend scenarios for Auburn supplies with Water District 111 and Covington are discussed below.

Blending Auburn Water with Water District 111

Water District 111 currently relies on six deep wells for its water supply and plans to develop interties with Auburn and Tacoma's Second Supply Pipeline (formerly known as Pipeline No. 5) to meet future demands (Water District 111, 1994). According to DOH (1994), Water District 111 did not exceed the lead or copper action levels during initial monitoring for the Lead and Copper Rule. Water District 111 treats its well water with a sequestering agent (sodium polyphosphate) to prevent oxidation and sedimentation of iron and manganese.

As discussed previously, polyphosphates generally are most effective at low pH values ranging from 5 to 7. If Auburn selects pH adjustment for corrosion control, then the treated Auburn supply may adversely affect Water District 111 when blended together by shifting the water pH and diluting the polyphosphate concentration. If Auburn selects orthophosphates or silicates for corrosion control, then the water chemistry may not be compatible and the treatments may not be effective when the supplies are blended together. Water District 111 should evaluate the impact of importing and blending treated Auburn water based on the final treatment recommendation of this desktop evaluation.

In addition to corrosion control treatment, Water District 111 also should evaluate the potential impacts of dissolved oxygen and chlorine residual when blending Auburn water into its system. Although data were not available for Water District 111 sources, the dissolved oxygen levels of Water District 111 wells likely are less than the Auburn supply. The process of blending these supplies in Water District 111 may adversely affect areas of the system which may be constructed with unlined cast iron or unlined steel pipe materials. The chlorine residual in the Auburn supply also may adversely affect Water District 111 water quality by potentially oxidizing iron or manganese. These blending issues should be examined in detail by Water District 111 prior to implementing the proposed intertie with Auburn.

Blending Auburn Water with Covington Water

Covington Water District relies on ground water from the Lake Sawyer and Witte Road well fields to meet current demand and plans to develop interties with Auburn and Tacoma's Second Supply Pipeline for future supplies (Covington Water District, 1994). Water produced from the Witte Road well field exhibits high levels of manganese, which is removed by oxidation and greensand filtration. Although data were not available, dissolved oxygen

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levels in Covington ground water sources are expected to be lower than the Auburn supply. Further, Covington currently does not disinfect its sources.

During initial monitoring for the Lead and Copper Rule, Covington exceeded the action level for copper (and did not exceed the action level for lead). Covington currently is conducting a corrosion control study in compliance with the requirements of the Lead and Copper Rule. Depending on the outcome of this study, Covington may implement a form of corrosion control treatment that would increase the pH of finished water. The corrosion control study is expected to be completed by July 1995 and treatment (if required) is expected to be implemented by January 1998.

If Auburn and Covington both select pH and/or alkalinity adjustment as the optimal corrosion control treatment for their respective systems, then the pH of the two systems will be compatible after treatment. However, if the two systems select different treatment alternatives, then Covington may be required to conduct additional studies to evaluate the water compatibility of the two systems.

Blending Auburn Water with Other Systems

Auburn currently provides water to the City of Algona during peak flow and to the City of Pacific on an emergency basis, and is considering service to the Lakehaven Utility District in the future. Algona serves a population less than 2,000 with an average demand of approximately 100 gpm. Algona's facilities include one well, chlorine disinfection, and one 100,000 gallon storage tank (Algona, 1989). The City of Pacific serves a population less than 5,000 and relies on one well with chlorine disinfection treatment (Pacific, 1990). Since Auburn provides service to these communities on an as needed basis, the type of corrosion control treatment selected by Auburn is not expected to impact significantly water quality in either of these two systems. If Auburn decides to provide service to Lakehaven in the future, a blending study should be conducted to evaluate the impact of Auburn's corrosion control treatment on water quality in the Lakehaven system.

5.2.5 Interference with Existing Treatment

Auburn currently disinfects water produced from the Coal Creek and West Hill springs by gaseous chlorine injection. As discussed previously, free chlorine disinfection is most effective at lower pH values. If Auburn selects a corrosion control treatment that involves an increase in water pH, then the chlorine gas injection should occur prior to the addition of chemicals for the pH adjustment to maximize disinfection efficiency.

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5.2.6 Operational Constraints

The selection of an optimal corrosion control treatment alternative must be appropriate for the Auburn system and its implementation should account for current and future operations. These operational constraints are discussed below.

Appropriateness of Technology

Although a variety of technologies are available to water systems for corrosion control treatment, only certain technologies may be appropriate for the Auburn system. Specific operational concerns may include the size of the system, additional staff training or certification, chemical hazards, and reliability. The appropriateness of available technologies and operational concerns are summarized on Table 5-7.

Table 5-7
Summary of Appropriateness and Operational Concerns for Corrosion Control Treatment Alternatives[1]

Treatment Alternative	Technology	Appropriateness of Technology	Operational Concerns
pH/Alkalinity Adjustment	Caustic Soda (NaOH)	Well suited for small to medium sized water sources; Chemical is supplied in liquid form and it is easy to add to existing facilities; Low capital cost and low to moderate chemical cost; Most commonly used alkali-chemical for corrosion control treatment of well sources in the Pacific Northwest.	Hazardous chemical with pH of 14; Special fire and building code permits are required for storage of 10 gallons or more; Solution has a high freezing point (e.g., 50 percent solution is 54°F); Chemical storage and piping needs to be protected from cold weather.
	Lime ($Ca(OH)_2$)	Most suitable for large water supplies; Moderate to high capital cost and low chemical cost; Calcium helps with scale formation in pipe and provides a corrosion barrier.	Dust can be a health concern; Special fire and building code permits are required to store or use 100 pounds or more; Lime is a dry chemical and it requires more equipment compared to liquid feed; Operation and maintenance of equipment is more labor intensive compared to liquid feed; Scale buildup in pipe may become excessive and reduce hydraulic flow in the system.
	Soda Ash (Na_2CO_3)	Suitable for systems that need to raise both pH and alkalinity, particularly small systems; Chemical costs are greater than lime; Soda ash is easier to feed compared to lime.	Chemical is considered nonhazardous; Dust may be a problem during operation.

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Table 5-7 (continued)
Summary of Appropriateness and Operational Concerns for Corrosion Control Treatment Alternatives[1]

Treatment Alternative	Technology	Appropriateness of Technology	Operational Concerns
	Sodium Bicarbonate	Used to increase alkalinity in conjunction with an alkaline chemical for pH adjustment; If used alone, chemical treatment will not exceed pH 8.4; Chemical costs are greater than soda ash for increasing alkalinity.	Chemical is considered nonhazardous; Excessive mass of chemical would be required to feed sodium bicarbonate for pH adjustment.
	Limestone Contactors	Suitable for small systems with flow less than 100 gpm.	Chemical is nonhazardous; Concern with disposal of backwash water.
	Aeration	Suitable for systems with carbon dioxide levels greater than 15 mg/L. Most suitable for small medium systems (>0.5 MGD). High capital costs, but very low chemical costs. Higher utility costs than liquid or dry chemical feed.	pH adjustment limited to amount of carbon dioxide present in source. Low maintenance and operational requirements. Also strips VOCs and radon, oxidizes iron and manganese.
Corrosion Inhibitors	Phosphate Addition	Most effective on metal surface where there is very little existing scale; Capital costs are low, the liquid form is easy to install and simple to feed; Ortho/polyphosphate blends may be used to sequester iron and manganese.	When there is existing scale, orthophosphate can cause existing scale to slough for an extended period of time; An initial passivating dose (approximately 2 to 5 times the maintenance dose) is required for 4 to 6 weeks; May adversely affect biological stability in open reservoirs; Blending treated and untreated water may increase corrosion in the mixing zone; Pitting corrosion can increase if dosage is inadequate; Phosphates have limited effectiveness in dead end zones; Zinc orthophosphate is a health concern, it requires special fire and building permits, and it can affect wastewater treatment plants.
	Sodium Silicate	Chemical has been used for corrosion control for copper and galvanized steel, particularly in hot water systems; very little data is available for lead pipe and lead/tin solder; Capital costs are low, the liquid form is easy to install and simple to feed;	Protective clothing and equipment should be used during handling due to high pH of chemical; Spilled sodium silicate is slippery and needs to be cleaned up immediately; An initial passivating dose (approximately 2 to 5 times the maintenance dose) is required for 3 to 8 weeks; Chemical storage and piping needs to be protected from cold weather.
Calcium Hardness Adjustment	Calcium Carbonate ($CaCO_3$)	Most appropriate for areas with hard water; thus, this treatment is not considered suitable for the Pacific Northwest.	Process must be carefully controlled to reduce the risk of excessive scaling in the system.

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[1] *Based on information provided by Larsen (1994).*

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Treatment Implementation

Several options should be considered for implementing corrosion control treatment in the Auburn system. For example, corrosion control treatment could be implemented by constructing a central facility and routing all of Auburn's source water through the central location prior to distribution. This option is not considered viable based on the extensive piping and pumping modifications that would be required to implement this plan. Alternatively, corrosion control treatment could be implemented by installing treatment facilities at every wellhead and spring source. Although this plan may seem feasible at first glance, it has been evaluated further and characteristics which are particular to the Auburn system have been identified to reduce the overall cost of implementation.

5.2.7 Specific Water Quality Goals

Depending on the technology selected, the implementation of corrosion control treatment may impact Auburn water quality characteristics in a manner which is not directly covered by drinking water regulations. For example, certain chemical treatments may increase the sodium level, affect the potential for iron and manganese precipitation, or disrupt system equilibrium. These specific water quality concerns are discussed below.

Sodium

Many of the chemical alternatives for corrosion control treatment will result in elevated levels of sodium in finished water. pH and alkalinity adjustments can be accomplished by adding sodium bicarbonate, sodium carbonate, or sodium hydroxide (or potassium hydroxide). Some orthophosphate inhibitors contain sodium in place of zinc and silicate inhibitors can occur as a sodium salt. Although there is no MCL for sodium for water systems in the State of Washington, a limit of 20 mg/L has been recommended by the USEPA for consumers who maintain low sodium diets. Naturally-occurring sodium concentrations exhibited by Auburn sources range from 3 to 19 mg/L and are summarized on Table 5-8 below.

Depending on the treatment selected, the sodium concentration in Auburn water potentially could exceed 20 mg/L as a result of corrosion control treatment, especially for Wells 2, 3A and 3B. If sodium-based chemicals (e.g., caustic soda) are used to adjust pH, the level of sodium in finished water may be significantly greater than existing conditions. All water systems with sodium levels greater than 20 mg/L are required to inform local health authorities of the change in water quality. The addition of sodium to the water supply probably would not result in serious health concerns; however, a public notification/education program may be necessary.

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Table 5-8
Auburn Water System
Sodium Concentrations for Auburn Sources[1]

Source Name	DOH ID #	Sodium (mg/L)
Coal Creek Springs	S01	3-5
West Hill Springs	S02	5-8
Well 1	S03	5-6
Well 2	S04	8-14
Well 3A	S05	8-17
Well 3B	S08	8-19
Well 4	S06	4-7
Well 5	S07	4-7
Well 5A	S09	6
Hidden Valley[2]	S01	5

[1] *Based on samples collected from 1987 to 1994.*

[2] *Hidden Valley is a satellite system which is operated by the City of Auburn, but it is not connected to the Auburn distribution system.*

As an alternative to sodium-based chemicals, Auburn may consider the use of potassium hydroxide for pH adjustment in the system. The advantages of using potassium hydroxide are the absence of sodium and the low freezing point of the chemical (–19°F for a 45 percent solution) . Certain utilities in New England (e.g., Northborough, Bedford, and Peabody) currently use potassium hydroxide for pH adjustment of drinking water for the reasons stated above. In general, these utilities are pleased with storage, handling, and the effectiveness of potassium hydroxide in their systems (Buzanoski, Churchill, and Smyrnioff, 1995). The disadvantage of potassium hydroxide is the higher cost of the bulk chemical compared to caustic soda.

Iron and Manganese

Iron and manganese concentrations exhibited by Auburn sources were summarized previously on Table 5-5. In general, Auburn sources exhibit iron and manganese levels less than the secondary MCLs, except for Wells 3A and 3B. These wells only are used during peak demand periods and customers are notified in advance.

Polyphosphates can be used to sequester iron and manganese for certain water sources. If Auburn selects polyphosphates for corrosion control treatment, then the polyphosphate treatment could be used to sequester iron and manganese in Wells 3A and 3B. However, the use of polyphosphate may increase lead concentration by sequestering it in the bulk water phase.

According to metals solubility theory, an increase in pH has the effect of decreasing the solubility of iron and manganese, which can result in metals

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precipitation. Thus, a pH increase potentially could aggravate iron and manganese precipitation in water produced from Wells 3A and 3B.

Disruption of System Equilibrium

During the start up of corrosion control treatment, Auburn may be required to increase the frequency of water main flushing to mitigate the effects of changes in the system equilibrium. A consumer education program also could be planned to inform customers of the situation and provide suggestions for flushing turbid water from home plumbing systems. The occurrence of these problems should diminish significantly after a few months of operating the new corrosion control treatment.

5.2.8 Summary of Functional Constraints and Secondary Issues

Functional constraints and secondary impacts that may affect Auburn's selection of a corrosion control treatment alternative are summarized on Table 5-9. The relative level of concern for each impact also is listed.

Table 5-9
Auburn Water System
Summary of Functional Constraints and Level of Concern

Functional Constraint	Level of Concern
Planning Considerations	
Plans for new wells and new pump station should be integrated with plans for corrosion control treatment, but these plans are not expected to influence selection of treatment alternative.	Medium
Blending of Multiple Sources	
The Lakeland Hills pressure zone is served exclusively by Wells 5 and 5A, which exhibit higher radon levels compared to Auburn sources. If pH adjustment is selected by Auburn for corrosion control treatment, then the radon levels may influence Auburn's selection of a specific treatment technology (e.g., aeration).	High
Wells 3A and 3B exhibit iron and manganese levels greater than the secondary MCLs and are pumped into the Valley and Lea Hill pressure zones during peak demand periods only. Iron and manganese precipitation could be exacerbated if pH adjustment is selected by Auburn for corrosion control.	High
If an ortho-polyphosphate blend is selected by Auburn to control corrosion and sequester iron and manganese from Wells 3A and 3B, then iron and manganese could be a concern for customers in home hot water heaters and on laundry when bleach is used.	High

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Table 5-9 (continued)
Auburn Water System
Summary of Functional Constraints and Level of Concern

Functional Constraint	Level of Concern
Impacts on Service Community	
pH adjustment, corrosion inhibitors, and calcium precipitation are all considered safe treatments by the USEPA for corrosion control in drinking water systems.	Low
If pH adjustment is selected by Auburn for corrosion control treatment, the impact of the treatment on chemical dosage requirements for cooling and heating systems is expected to be negligible. If the pH is increased above 8.0, then biocide treatment may need to be modified.	Low
If a silicate-based inhibitor is selected by Auburn for corrosion control treatment, then silica removal may be required by some facilities that require high purity water.	Medium
Impacts on Consecutive Systems	
If Auburn selects pH adjustment for corrosion control treatment, then the treated Auburn water may adversely affect Water District 111 which uses sodium polyphosphate to sequester iron and manganese.	Medium
If Auburn selects a phosphate-based inhibitor for corrosion control treatment, then the treated Auburn water would not be compatible with planned corrosion control treatment for the Covington Water District.	Medium
If Auburn selects pH adjustment for corrosion control treatment, then the treated Auburn water would be compatible with current operations and planned corrosion control treatment for the Covington Water District.	Medium
Interference with Existing and Future Treatment	
pH adjustment may require an increase in disinfectant contact time or residual concentration.	Medium
Operational Constraints	
If either pH adjustment or inhibitor treatment is selected by Auburn, then treatment will be required for multiple sources located throughout the system. However, more treatment sites likely will be required for inhibitor treatment to maintain a uniform concentration of the inhibitor in the distribution system.	High
Specific Water Quality Goals	
Public education regarding sodium levels may be necessary, potential for iron and manganese precipitation, system equilibrium disruptions	Low/Medium

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Section 6
Elimination of Unsuitable Approaches

The term "corrosion control" historically has been applied to a variety of water treatment techniques which have been used to meet different water quality objectives. Until recently, corrosion control practices by water systems were typically designed to protect hydraulic capacity, reduce long-term pipeline maintenance, and improve aesthetics by reducing red water. Although these objectives remain worthwhile, they may not directly address Lead and Copper Rule compliance, which essentially has redefined corrosion control primarily on the basis of public health impacts. The objective of the LCR is to minimize the concentration of lead and copper in drinking water without compromising other health-related water quality goals. This has created some confusion where long-standing corrosion control procedures are now being found "ineffective" with respect to the new objectives.

A wide variety of proprietary chemicals have evolved to control pipeline deterioration, eliminate "dirty water" complaints, reduce laundry staining, etc. Some of these "corrosion inhibitor" chemicals also can help reduce lead and copper levels in drinking water, although many will not, and some could even increase lead concentrations. Comparison of corrosion inhibitors is often controversial because of the proprietary nature of the specific chemical formulations. This issue is further complicated by a lack of understanding by many users about the differences between chemical products (e.g., ortho- and poly-phosphates) and their relationship to the formation of metallic precipitates and protective films in potable water systems. The use of chemical treatment to reduce lead and copper in drinking water will depend upon many chemical and physical interrelationships and usually requires side-by-side testing to assess performance.

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6.1 Summary of Treatment Alternatives

At a minimum, the Lead and Copper Rule mandates that utilities consider three basic approaches for achieving corrosion control:

☐ pH/alkalinity adjustment;
☐ Calcium adjustment ($CaCO_3$ deposition); and
☐ Inhibitor addition.

Characterizing corrosion control in this fashion tends to oversimplify the range of options available to a utility when tailoring a program to its specific needs. A more accurate approach is to recognize that corrosion control technologies can be characterized by two general mechanisms, each of which has a multitude of variations that carry specific advantages and disadvantages. The two mechanisms are known as barrier protection and passivation, and each mechanism is defined below.

❒ Barrier Protection—The deposition of a precipitate film on the plumbing surfaces to prevent oxidizing agents in the water from reaching the pipe wall and/or oxidized metals from the pipe wall from releasing into the water.

❒ Passivation—The manipulation of water quality so as to cause plumbing materials and a number of water constituents to form less soluble metal complexes and/or insoluble oxide layers that change the electrochemical nature of the metal surface and limit the underlying rate of the corrosion process.

As summarized in Table 6-1, various chemical treatment systems are available to promote barrier protection and/or passivation. Each of these systems must be evaluated relative to dosage range and specific water quality concerns. Moreover, it should be realized that a particular treatment system will not be universally effective on all metal types, and that corrosion control must be tailored to the plumbing material of interest. In the evaluation of materials susceptible to corrosion in the Auburn system, copper and copper containing materials such as brass were rated as the highest priority for corrosion control treatment. However, a corrosion control treatment approach for copper must not increase corrosion rates on other metal surfaces in the distribution system such as lead, iron, steel, and galvanized piping.

Table 6-1
Conceptual Framework for Corrosion Control Approaches

Control Mechanism	Barrier Protection	Passivation	
Treatment Approach	calcium adjustment	pH/alkalinity adjustment	corrosion inhibitor
Key Water Quality Parameters	calcium pH/alkalinity TDS, temperature	pH/alkalinity TDS temperature	pH/alkalinity hardness, temperature metals
Appropriate Chemical Feed Systems	lime soda ash sodium bicarbonate caustic soda carbon dioxide	lime soda ash sodium bicarbonate caustic soda carbon dioxide	orthophosphate polyphosphate phosphate blends silicates silicate/phosphate blends

Source: Lead and Copper Rule Guidance Manual, Volume II (1992).

The secondary corrosion control impacts associated with each potential strategy must also be evaluated, including compatibility with future and planned

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disinfection practices, impacts on microbial regrowth within the distribution system, commercial and industrial water users, hospitals and other medical facilities, and potential impacts to wastewater treatment plant operations and wastewater NPDES discharge permit status. Additional discussion regarding the three corrosion control treatment approaches and their potential impacts on water systems is included as Appendix B.

6.2 Determination of Viable Alternatives

The purpose of this section is to eliminate unsuitable corrosion control treatment approaches so that only viable alternatives are evaluated in detail for the remainder of this study. The elimination of unsuitable treatment approaches is based on data and information discussed previously regarding the configuration of the Auburn system, water quality, regulatory and functional constraints, number and location of water sources, interties with other systems, blending of different water qualities within the Auburn system, and specific customer concerns. The applicability of each of the three corrosion control treatment approaches to the Auburn system is discussed below.

6.2.1 pH/Alkalinity Adjustment

Data and information indicate that the alkalinity of Auburn water falls within the optimal range for copper corrosion control (AWWA and WITAF, 1993) and low pH is the major cause of copper corrosion in the Auburn system. Accordingly, alkalinity adjustment will be eliminated as a treatment approach because any adjustment in alkalinity likely would not decrease the existing rate of copper corrosion in the Auburn system. Conversely, an increase in pH likely would decrease the rate of copper corrosion and therefore will be considered in more detail as a viable treatment approach for the Auburn system.

6.2.2 Calcium Adjustment

Exhibit 6-1 is a graphical summary of USEPA's suggested treatment approaches for corrosion control in a system based on water quality characteristics. Exhibit 6-1 is divided into several zones based on pH, alkalinity, and calcium concentration. As discussed previously, water from Auburn sources exhibit low pH, low-moderate alkalinity, and low-moderate calcium concentration. By correlating these water quality characteristics with the zones on Exhibit 6-1, the suggested corrosion control treatments for Auburn include carbonate passivation (pH/alkalinity adjustment), phosphate and silicate inhibitors. Calcium carbonate precipitation is not included as a suggested treatment approach. Based on these USEPA guidelines, the

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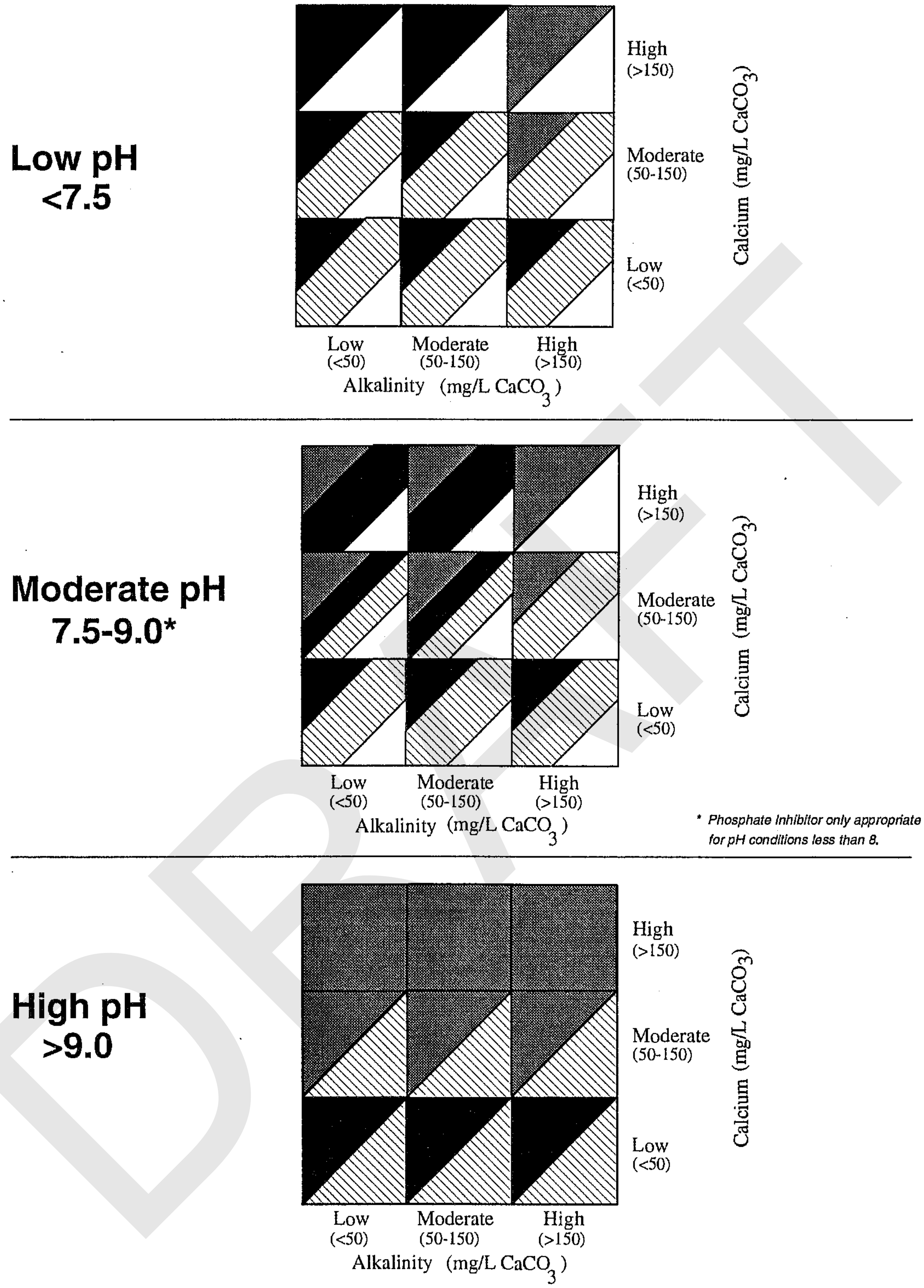

** Phosphate Inhibitor only appropriate for pH conditions less than 8.*

Exhibit 6-1. Suggested Corrosion Control Approaches Based on Water Quality Characteristics

▩ = **Calcium Carbonate Precipitation**	☐ = **Phosphate Inhibitor**
■ = **Carbonate Passivation**	▨ = **Silicate Inhibitor**

Source: LCR Guidance Manual, Volume II

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calcium carbonate passivation approach will be eliminated from further consideration as a viable treatment approach for the Auburn system.

6.2.3 Corrosion Inhibitors

Orthophosphate inhibitors are most effective for lead and copper corrosion control within a narrow pH range of 7.4 to 7.8. Available data and information from analogous systems (City of Renton and Covington Water District) indicate that orthophosphates can be effective for controlling copper corrosion in nearby water systems. If Auburn selects orthophosphates as the preferred corrosion control treatment, then Auburn will need to increase the source water pH to approximately pH 7.5 and maintain that pH throughout the distribution system. For low-moderately buffered systems such as Auburn, pH fluctuations can occur within the distribution system and the operation of an orthophosphate addition system likely will require a higher level of process monitoring and control.

Results from bench-scale testing conducted by the Covington Water District in 1994 indicate that silicate dosages as high as 30 mg/L as SiO_2 were demonstrated only marginally effective for copper corrosion control. Recent studies also suggest that corrosion control by silicate-based inhibitors may not be as effective as previously believed for the control of copper corrosion, and that any improvement in copper corrosion may be attributed to the pH increase that accompanies the silicate treatment (Reiber, 1994). In addition, there is little known data regarding the effectiveness of field-tested silicate-based inhibitors for copper corrosion control in the Pacific Northwest. Based on these data and information, the use of silicate-based inhibitors will be eliminated as a viable treatment approach for the Auburn system.

Based on the preceding evaluation of corrosion control treatment alternatives, two of the treatment alternatives will be considered viable treatment approaches for the Auburn system: pH adjustment and phosphate addition. These two treatment approaches are evaluated in more detail in the following section.

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Section 7
Evaluation of Viable Treatment Alternatives

The purpose of this section is to evaluate viable corrosion control treatment alternatives and determine optimal corrosion control treatment for the Auburn system. This section focuses on pH adjustment and phosphate inhibitors and includes an evaluation of these two viable treatment alternatives based on four criteria outlined in the Guidance Manual for the Lead and Copper Rule. These four criteria include performance, constraints, reliability, and costs and are described below.

☐ Corrosion control **performance** based on reductions in metal solubility or the likelihood of forming a protective scale. Performance can be based on theoretical calculations, bench scale tests, pilot plant testing, and the experience of other systems already practicing optimized corrosion control.

☐ The feasibility of implementing treatment alternatives based on regulatory and functional **constraints**. Regulatory constraints include existing federal and state drinking water standards as well as anticipated regulations that may impact the system in the future. Functional constraints pertain to the impact of the treatment alternatives on the following: the existing system; industrial, commercial, and domestic water users; and wastewater treatment facilities downstream.

☐ The **reliability** of the treatment alternatives in terms of operational consistency and continuous corrosion control protection. The advantages and disadvantages of the available chemical feed systems should be considered including the ability to minimize interruptions in treatment due to maintenance, chemical inventory problems, or equipment and instrumentation failure. The LCR requires that corrosion control treatment be operated continuously.

☐ The estimated **costs** associated with implementing the treatment alternatives. Costs for a corrosion control treatment system should be amortized over the expected life of the feed system and include capital expenditures, chemical costs, and operations and maintenance costs.

7.1 Corrosion Control Performance

The overall effectiveness of pH adjustment and phosphate inhibitors are based on the likelihood of success and the extent that copper and lead release can be reduced below

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current levels. This performance evaluation is based on data and information obtained from theory, field testing, and analogous system experiences.

7.1.1 Theory

Unlike lead concentrations at-the-tap, which are attributed to dissolved and particulate lead materials in water, theoretical copper solubility relationships provide a better basis for predicting the effects of corrosion control treatment on copper concentrations at-the-tap. Exhibit 7-1 illustrates the theoretical relationship of copper solubility as a function of pH and dissolved inorganic carbon (DIC). Data collected during initial monitoring for the LCR indicate pH values ranging from 6.3 to 6.5 and DIC values ranging from 11 to 24 mg/L as C for the Coal Creek springs, Well 1, Well 2, and Well 4. Based on relationships shown on Exhibit 7-1, water quality data for Auburn sources correlate with theoretical copper solubility values ranging from approximately 4 to 28 mg/L under current conditions. For pH 7.0 and the same DIC range, the theoretical copper solubility is estimated to range from approximately 2.0 to 3.2 mg/L. For pH 7.5 and the same DIC range, the theoretical copper solubility is estimated to range from 0.5 to 1.0 mg/L. These calculations suggest that the copper solubility of newer pipe can be reduced by as much as 93 percent by raising the pH of Auburn water to 7.0, and as much as 98 percent by raising the pH to 7.5. Thus, based on theory, the greatest reduction in copper concentration at-the-tap is expected to occur as a result of increasing the pH from 6.5 to 7.0. A pH increase from 7.0 to 7.5 likely will further reduce copper concentrations at the tap, but the reduction in copper corrosion will be less than the effect of the pH increase from 6.5 to 7.0.

The data included on Exhibit 7-1 are plotted in three-dimensional form on Exhibit 7-2. Here the theoretical effect of pH on copper solubility is evident in the way the graph slopes downward as pH increases. Theoretically, copper solubility continues to decrease as pH increases to a pH of 9 for DIC concentrations ranging from 0 to 150 mg/L as C.

In a recent study, Schock et al. (1994) observed a declining trend in copper solubility as a function of increasing pH for older pipe and pH in the range of 6.0 to 9.0 (Exhibit 7-3). Older pipe was characterized by the formation of $Cu_2(OH)_2CO_3(s)$ (also known as malachite) on the internal pipe wall and newer pipe was characterized by the absence of malachite. For a pH increase from 6.5 to 7.0, the copper solubility was reduced from 0.32 to 0.08 mg/L, or a copper solubility reduction of 75 percent.

For newer pipe, the investigators observed that treatment with 1 to 5 mg/L of orthophosphate was more effective than pH adjustment alone for pH less than 8.0, but orthophosphates were no more effective than pH adjustment alone for pH greater than 8.0. For the Auburn system, these results suggest that orthophosphate addition may be effective for reducing copper corrosion

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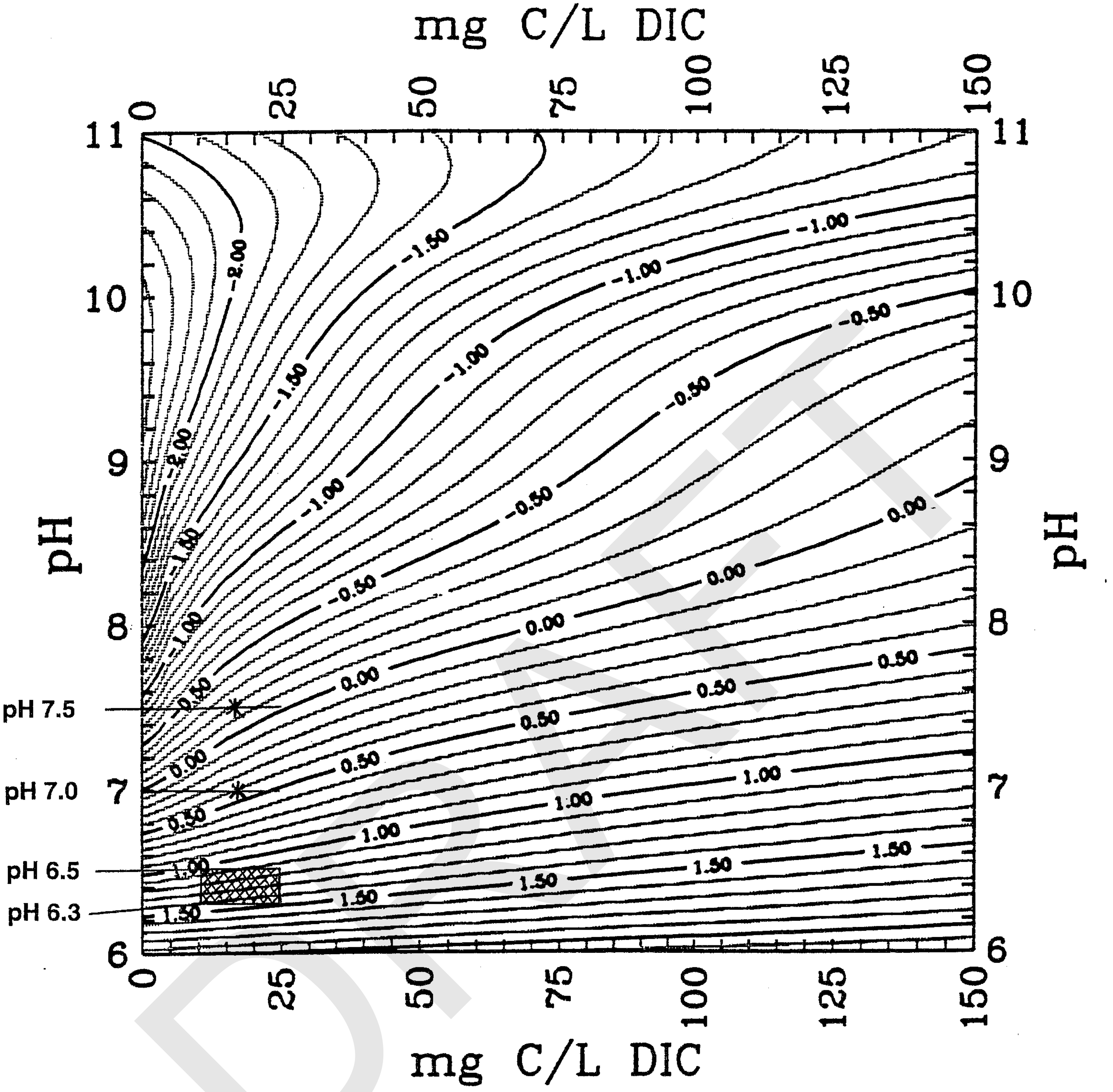

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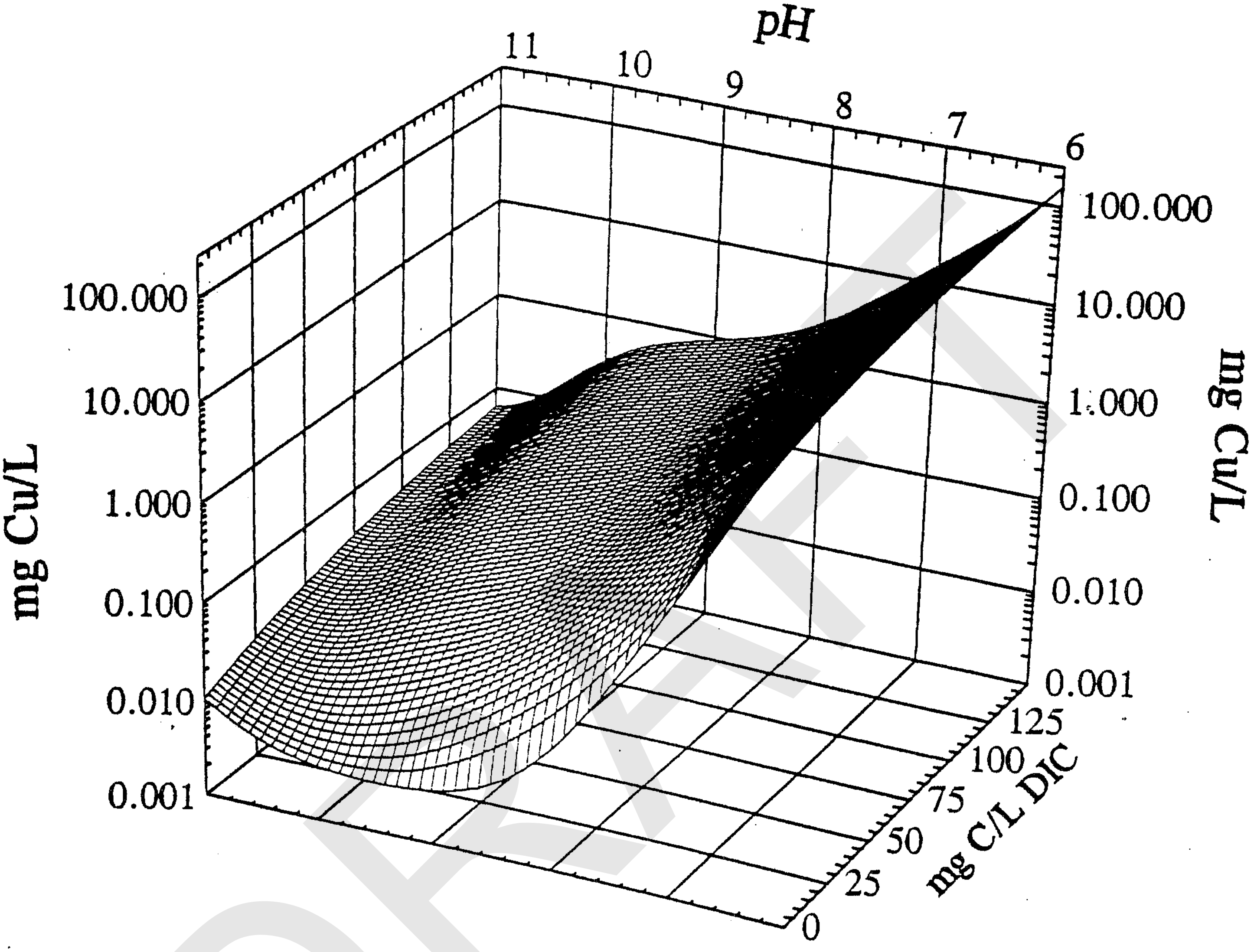
Contour diagram showing the effect of pH and DIC on the solubility of $Cu(OH)_2(s)$ with a large molar surface, assuming I = 0.02, at 25 ° C. Contour units are log(mg Cu/L).

Source: Effect of pH, DIC, and Orthophosphate on Drinking Water Cuprosolvency, Schock et al. (1994).

Exhibit 7-1

Two-Dimensional Copper Solubility
No Phosphates



Three-dimensional surface plot of the effect of DIC and pH on copper(II) solubility, assuming equilibrium with $Cu(OH)_2(s)$ having a large molar surface (I = 0.02, 25 ° C).

Source: Effect of pH, DIC, and Orthophosphate on Drinking Water Cuprosolvency, Schock et al. (1994).

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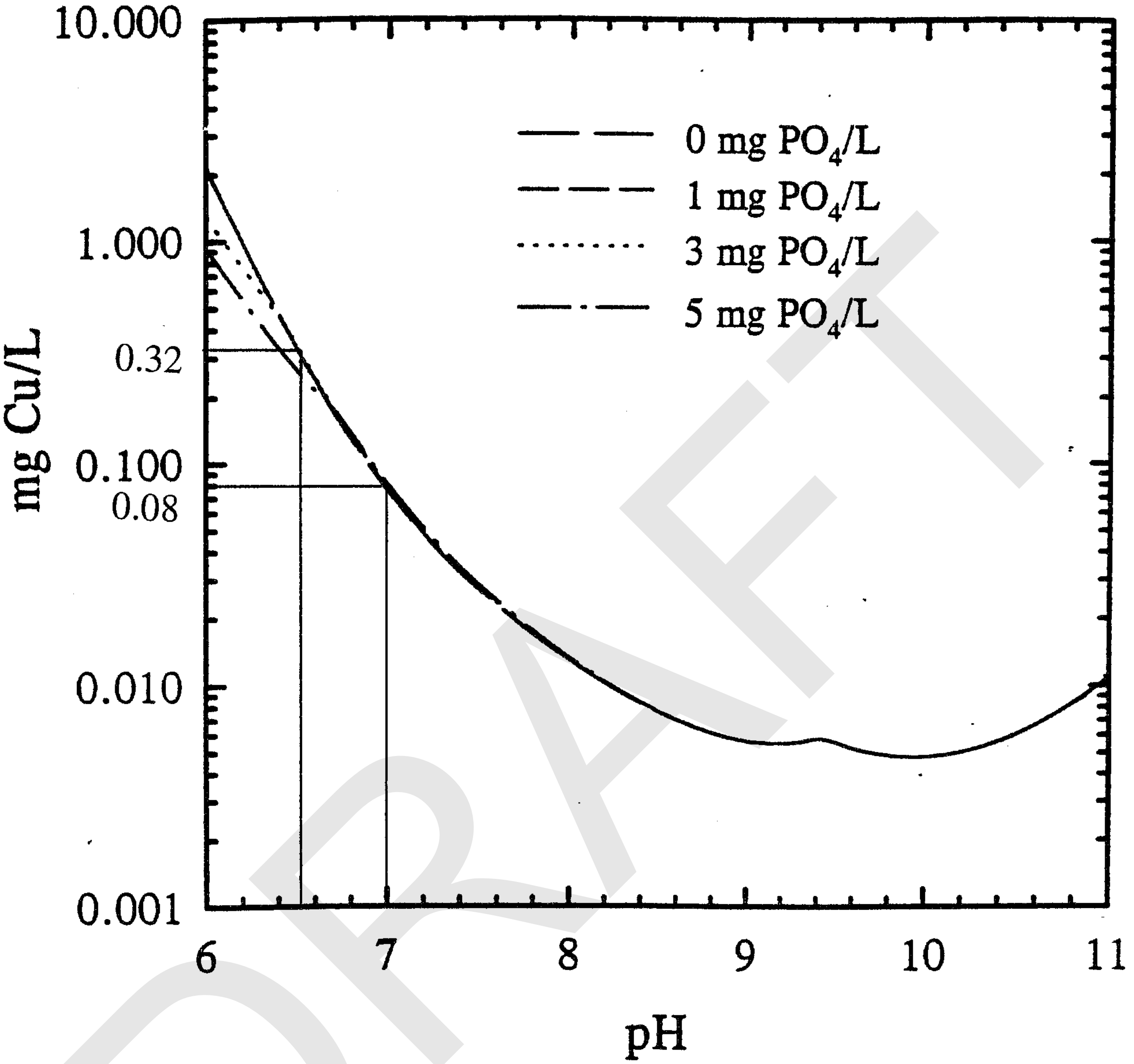
Exhibit 7-2

Three-Dimensional Copper Solubility
No Phosphates



Effect of orthophosphate on copper(II) solubility at DIC = 4.8 mg C/L, I = 0.005 and 25 ° C, assuming formation of $Cu(OH)_2(s)$, $Cu_2(OH)_2CO_3(s)$, and $Cu_3(PO_4)_2 \cdot 2H_2O(s)$.

Source: Effect of pH, DIC, and Orthophosphate on Drinking Water Cuprosolvency, Schock et al. (1994).

Exhibit 7-3

Effect of pH and Orthophosphate on Copper Solubility for Older Pipe

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in areas which contain new copper pipe and are served with low pH water (less than approximately 7.5-8.0). However, orthophosphate addition would not be expected to reduce significantly copper corrosion in areas which contain older pipe, regardless of the pH of the water.

7.1.2 Analogous System Experience

Bench-scale, pilot-scale, and full-scale testing by analogous systems indicate that pH adjustment can be an effective treatment for reducing copper corrosion rates and copper concentrations at the tap. For analogous systems in the Pacific Northwest, bench-scale testing was conducted by the Covington Water District in 1994 and results indicated a meaningful reduction in copper corrosion rate when the pH was increased from 6.8–7.2 to 7.8–8.2. Similarly, bench-scale tests conducted by the City of Renton in 1994 indicated a reduction in copper corrosion rate when the pH was increased from 7.2-7.4 to 7.7-8.1. The Cities of Seattle, Vancouver, Washington and Portland, Oregon also observed significant reductions in copper corrosion and at-the-tap copper concentrations by increasing water pH. These data show that raising the pH above 7.5 reduces copper corrosion at the tap.

Although analogous system data for the Pacific Northwest are limited regarding the effects of increasing water pH from 6.5 to approximately 7.0, available data and information indicate reductions in copper corrosion as pH is increased. Thus, by increasing the pH of Auburn water from 6.5 to approximately 7.0, copper concentrations at the tap are expected to decrease accordingly.

Although Pacific Northwest data were not available for comparison to the Auburn system for pH in the range of 6.5 to 7.0, national WITAF survey results suggest a strong relationship between pH and copper release in this low pH range. Survey results include systems that did not add phosphate inhibitor with pH values ranging from 6.5 to 9.5. Median copper concentrations for systems within this pH range are summarized below.

pH range	Median Copper (mg/L)
6.5-7.0	0.95
7.0-7.5	0.35
8.0-8.5	0.17
9.0-9.5	0.03

These survey results indicate a declining median copper concentration at-the-tap as the pH increases from 6.5 to 9.5.

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In addition to pH adjustment alone, data and information from analogous systems indicate that the addition of orthophosphates with simultaneous pH adjustment to 7.5 can be used for copper corrosion control. Bench-scale tests conducted by Covington indicate that orthophosphate addition with pH adjustment to 7.7-7.8 performed comparably to pH adjustment to 8.2-9.0. Bench-scale tests conducted by Renton indicate that phosphate addition with pH adjustment to 7.7 performed comparably to pH adjustment to 8.3-8.6. Bench-scale tests conducted by Seattle and pipe-loop tests conducted by Portland, Oregon also indicated reductions in copper corrosion with phosphate addition and pH at 7.5.

Theory, field testing, and analogous system data and information indicate that both pH adjustment and phosphate addition can be used as effective treatments for copper corrosion control, but pH adjustment is the preferred treatment for the Auburn system. Phosphate addition needs to be accompanied by an increase in pH to 7.5 to optimize the effectiveness of the phosphate treatment for reducing the solubility of copper (and lead). Above pH 7.5, phosphate addition is likely no more effective than pH adjustment alone. Furthermore, recent modeling studies (Schock et al., 1994) indicate that phosphate addition can reduce the uptake of copper from newer pipe surface, but phosphate addition may have little or no effect on copper uptake for older pipe surface. Therefore, based on performance, pH adjustment alone would provide equal or better long-term corrosion control treatment for the Auburn system compared to phosphate addition with pH adjustment to 7.5.

7.2 Regulatory and Functional Constraints

The most significant regulatory constraints that affect Auburn's selection of a corrosion control treatment alternative pertain to primary and secondary disinfection treatment, radon levels, iron and manganese, and disinfection by-products.

☐ Auburn currently is evaluating the classification of Coal Creek springs and West Hill springs as possible ground water sources under the influence of surface water per the Surface Water Treatment Rule. If either of these sources is determined to be a ground water under the influence of a surface water, then Auburn's selection of a corrosion control treatment may be constrained by a prescribed chlorine contact time for primary disinfection prior to the first customer served. If pH adjustment is selected by Auburn as the preferred corrosion control treatment, then an elevated pH may affect disinfection efficiency and require longer contact time or increased chlorine dosages for sources classified as GWUI or subject to the requirements of the GWDR. Auburn can account for these water quality concerns by appropriate design of primary disinfection facilities, if required.

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☐ In addition to primary disinfection, an increase in pH may reduce the effectiveness of chlorine residual in the distribution system. Auburn could mitigate this secondary disinfection concern by increasing the chlorine dosage or by minimizing the target pH for corrosion control. Many utilities operate with pH levels greater than 8.0 in the distribution system.

☐ The USEPA has proposed an MCL for radon of 300 pCi/L, but recent developments indicate that the final MCL may be established within the range of 200 to 1,000 pCi/L. Samples collected from Wells 5 and 5A, which serve the Lakeland Hills pressure zone, exhibited radon levels ranging from 710 to 825 pCi/L. Samples collected from Auburn sources which serve the Valley, Lea Hill, and Academy pressure zones exhibited radon levels ranging from 205 to 285 pCi/L. The selection of a corrosion control treatment alternative for the Auburn system should address the possibility of radon removal to meet the anticipated requirements of the Radon Rule.

☐ Water produced from Well 3A and Well 3B typically exhibits high levels of iron and manganese which are greater than the secondary MCLs. These wells typically are used only during peak demand periods. If a pH increase is selected as the optimal corrosion control treatment for the Auburn system, then precipitation of iron and manganese may be exacerbated in the Auburn system.

☐ Auburn consistently has reported total trihalomethane concentrations less than the current and anticipated MCLs. If pH adjustment is selected by Auburn as the preferred corrosion control treatment, then the potential for trihalomethane formation may increase. Based on mathematical modeling, Auburn is not expected to observe an increase in total trihalomethane concentrations beyond the anticipated MCL of 40 μg/L contained in Stage II of the Disinfectant/Disinfection By-Products Rule.

Major functional constraints that affect Auburn's selection of a corrosion control treatment alternative pertain to planning, compatibility with existing treatment and operations, and impacts on customers and consecutive systems.

☐ Auburn currently is planning to construct a new pump station for the Lea Hill pressure zone. The new pump station may be equipped with a booster chlorine feed system and it may provide a location for corrosion control treatment.

☐ Auburn currently is planning to develop new ground water sources (Wells 6 and 7). The new ground water sources are expected to exhibit water quality characteristics similar to existing sources and therefore are not expected to affect significantly Auburn's selection of the type of corrosion control

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treatment. However, these new ground water sources may influence Auburn's corrosion control strategy in the future. If these new sources become major supplies for the Auburn system, then Auburn may need to provide corrosion treatment or modify operations to account for the effects of the new ground water sources in the distribution system.

☐ Respondents to a survey conducted by Auburn expressed concern regarding the adverse impact of silica and the possible impact of pH adjustment on treatment requirements for cooling and heating systems. The use of silicates could result in increased water and chemical costs for boilers and cooling systems to prevent formation of scales. The use of silicates also could result in increased capital costs to remove the added silica for facilities requiring high purity water. The use of sodium-based chemicals (e.g., caustic soda) would not present a concern for increased scaling in boilers or cooling systems, but an increase in pH above 8.0 may require modifications to biocide treatments.

☐ The low pH of Auburn's sources likely is the primary factor contributing to the corrosivity of the water supply to copper piping in the Auburn system. Corrosion control treatment likely will be needed for multiple sources to meet the requirements of the Lead and Copper Rule.

☐ If Auburn selects pH adjustment for corrosion control treatment, then the use of sodium-based chemicals (e.g., caustic soda) may result in unacceptable levels of sodium for certain customers.

☐ If a phosphate-based inhibitor is selected by Auburn for corrosion control, then treatment may be needed for every source to maintain a uniform phosphate concentration in the distribution system. Treatment may not be required for every source if pH adjustment is selected for corrosion control.

☐ Although phosphorus concentration currently is not limited for the Renton wastewater treatment plant, Metro staff would prefer to minimize phosphorus loading in the event that phosphorus limits are imposed on Renton in the future. Metro representatives have expressed a preference for pH adjustment compared to the use of inhibitors or calcium adjustment for corrosion control.

☐ If Auburn selects a phosphate-based inhibitor for corrosion control treatment, then Auburn would be required by DOH to install disinfection treatment in conjunction with the phosphate-based inhibitor.

☐ Auburn's selection of a corrosion control treatment will impact operations of consecutive systems, specifically Water District 111 and Covington Water District. Consecutive systems should evaluate the impact of blending treated water from Auburn with their own water as part of implementing interties.

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7.3 Reliability and Operability

The reliability of each treatment alternative is determined by the ability of the treatment to operate consistently and provide continuous corrosion control protection. Operability refers to operation, control, and maintenance requirements of the treatment alternative. Operability and reliability issues for each treatment alternative are summarized in Table 7-1.

Table 7-1
Evaluation of Reliability and Operability for Viable Treatment Alternatives

	Treatment Alternative		
Evaluation Criteria Category	**pH Adjustment**	**Phosphates with pH Adjustment to 7.5**	**Comments**
Reliability			
Expected Reliability of Treatment System	Good if control features are adequate.	Good if control features are adequate.	Reliability is a function of design and amount of redundant features. Both alternatives can consistently meet water quality objectives if adequate control features are provided.
Impacts on System in Event of Treatment Interruption	Possible negative impact due to sudden pH changes.	Somewhat better performance than pH adjustment.	Assuming interruption of up to 2 days, pH adjustment could result in increased lead and copper, and possibly iron release from scales. Possible public notification required if interruption is long.
Operability			
Operation and Staffing Requirements	Requirements are expected to be somewhat higher if solid chemicals are used. Number of treatment sites may be less than phosphates.	Requirements are expected to be somewhat higher if solid chemicals are used. Number of treatment sites may be greater than pH adjustment.	Solid chemical feed systems generally require more operational effort than liquid systems. Need to consider staffing and degree of remote treatment control and operations. Aeration would require less staffing than a solid or liquid feed system.
Relative Level of Maintenance for Treatment Equipment	Maintenance could be more difficult if solid chemical system is used.	Maintenance could be more difficult if solid chemical system is used.	Solid chemical feed systems require more maintenance. Aeration would likely require least maintenance.
Relative Safety of Chemicals and System Operation	Solid chemical systems require dust control. NaOH for pH adjustment requires careful handling.	No major concerns for phosphate chemicals, but same concerns for NaOH.	Chemicals are not unusually dangerous if proper handling of equipment and operations are practiced.

The comments on Table 7-1 indicate that pH adjustment and phosphate addition with pH adjustment to 7.5 are similar with regards to reliability and operability. Under certain conditions, such as a sudden interruption in treatment, pH adjustment may be somewhat less reliable than phosphate addition with pH adjustment due to the adverse impact of a sudden pH change on copper and lead solubility, and possible iron release into the system. The handling of solid chemicals or caustic soda may be a concern for treatment by pH adjustment, but the same chemical handling precautions apply to treatment by phosphate addition with pH adjustment to 7.5. Although these reliability and operability concerns are important, the differences between the two treatment alternatives are not significant enough to select one alternative over the other.

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7.4 Cost Comparison

Costs associated with the two viable corrosion control treatment alternatives (pH adjustment alone and phosphate-based inhibitors) were compared qualitatively. For pH adjustment alone, it was assumed that treatment facilities would be installed for the Coal Creek springs and Well 2 to attain a system-wide blended pH of 7.0. (See Section 8 of this report for a discussion on the basis for this assumption.) Furthermore, it was assumed that capital costs would be incurred for construction of new buildings and new treatment facilities for each of these two sources. Annual costs would include costs associated with chemical feed (e.g., caustic soda) and operation and maintenance (O&M).

For the phosphate-based inhibitor alternative, it was assumed that costs associated with buildings and treatment facilities for every Auburn source would be needed to provide uniform phosphate treatment throughout the distribution system. Additional costs would be incurred to raise the pH of water to 7.5 to minimize copper solubility in the distribution system and provide disinfection treatment. Annual costs would include phosphate-based chemicals, caustic soda, disinfectant, and O&M.

A qualitative comparison of system improvements associated with the two corrosion control treatment alternatives is shown on Table 7-2. The symbols indicate the type of improvements that would be needed for each of Auburn's sources to increase the system-wide pH to 7.0 or to add a phosphate-based inhibitor with a pH adjustment. It was assumed that treatment would not be needed for Wells 3A and 3B because they are supplemental sources used for emergencies only, or Wells 5 and 5A because they serve the Lakeland Hills exclusively (see Section 8 for further discussion). Based on this qualitative evaluation, costs associated with pH adjustment alone would be less than costs associated with the phosphate-based inhibitor alternative.

7.5 Conclusions

pH adjustment and phosphate-based inhibitor addition with pH adjustment to 7.5 are considered feasible corrosion control treatment alternatives for the Auburn system. The two treatment alternatives were evaluated based on the following criteria:

- ☐ Corrosion Control Performance,
- ☐ Regulatory and Functional Constraints,
- ☐ Reliability and Operability, and
- ☐ Costs.

Table 7-3 is a summary of the evaluation of the two treatment alternatives based on these four criteria.

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Table 7-2
Auburn Water System
Qualitative Summary of System Improvements Associated with Viable Corrosion Control Treatment Alternatives

		pH Adjustment to 7.5 at the Source				Phosphate-Based Inhibitor with pH Adjustment to 7.5 at the Source			
		Capital Costs		Annual Costs		Capital Costs		Annual Costs	
Site	Description	Building	Treatment Facilities	Chemical	O&M	Building	Treatment Facilities	Chemical	O&M
1	Coal Creek Springs	•	•	•	•	• ∇	• ∇	• ∇	• ∇
2	West Hill Springs					• ∇	• ∇	• ∇	• ∇
3	Well 1					• ∇ ♦	• ∇ ♦	• ∇ ♦	• ∇ ♦
4	Well 2	•	•	•	•	• ∇ ♦	• ∇ ♦	• ∇ ♦	• ∇ ♦
5	Wells 3A and 3B								
6	Well 4					• ∇ ♦	• ∇ ♦	• ∇ ♦	• ∇ ♦
7	Wells 5 and 5A								

• *pH Adjustment*
∇ *Addition of Phosphate-Based Inhibitor*
♦ *Disinfection Treatment*

Table 7-3
City of Auburn
Summary of Evaluation of Treatment Alternatives

Evaluation Criteria	Auburn Existing Conditions	pH Adjustment	Phosphate Addition with pH Adjustment	Best Alternative for Auburn
Performance				
Lead	Met AL	Effective	Effective	pH Adjustment
Copper	Exceeded AL	Effective	Effective	
Constraints				
Primary Disinfection	No Ct requirements	pH increase may reduce disinfection efficiency.	pH increase may reduce disinfection efficiency.	pH Adjustment
DBPs	Meets MCL	pH adjustment may increase slightly the formation of TTHMs	pH adjustment may increase slightly the formation of TTHMs	
Total Coliforms	Meets TCR	pH increase may reduce residual chlorine.	pH increase may reduce residual chlorine.	
Other Regulations	—	Aeration technology may be used for pH adjustment, radon and VOC removal.	Aeration technology may be used for pH adjustment, radon and VOC removal.	
Plans	New pump station for Lea Hill	May provide location for treatment.	May provide location for treatment.	
Multiple Treatment Sites	Plans to add disinfection treatment at multiple sites.	Number of treatment sites may be less than phosphates.	Number of treatment sites may be greater than pH adjustment.	
Water Quality	Good	Caustic soda may result in unacceptable sodium levels. May be able to use other chemicals or aeration.	Phosphate-based chemicals are not expected to pose a significant water quality concern.	
Wastewater Treatment	–	Metro staff prefer pH adjustment for corrosion control.	Metro staff would accept, but does not favor added phosphorus loading.	
Consecutive Systems	Auburn is planning to sell water to WD 111 and Covington	Compatible with Covington; not compatible with WD 111	Compatible with WD 111; not compatible with Covington.	
Reliability and Operability				
Treatment System	—	Good (with control systems)	Good (with control systems)	Both
Treatment Interruptions	—	May have negative impact on system equilibrium	Somewhat better than pH adjustment	
O&M Requirements	—	Minimal requirements with proper handling of liquid chemicals	Minimal requirements with proper handling of liquid chemicals	
Costs	—	Lower	Higher	pH Adjustment

7.6 Recommended Treatment

The recommended corrosion control treatment for the Auburn system is pH adjustment to a system-wide pH of 7.0, and possibly up to pH 7.5 if needed. This

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recommendation is based on theory, analogous system information and constraints as summarized below.

☐ pH adjustment has been used or is recommended for other utilities in the Pacific Northwest including the Covington Water District, the City of Seattle, the City of Vancouver, Washington and the City of Portland, Oregon.

☐ pH adjustment is compatible with Auburn's current operations and future plans for water quality improvement. Although currently below health standards, historical water quality data indicate low levels of VOCs in water from Well 2. Samples collected for Wells 5 and 5A in 1994 indicate radon levels ranging from 710 to 825 pCi/L. pH adjustment for the Auburn system would be compatible with future water quality treatment (e.g., aeration for VOC or radon removal), if necessary.

☐ Water quality data for Coal Creek springs, Well 1, Well 2, and Well 4 indicate pH values the range of 6.3-6.5. Based on theory, a pH increase to 7.0 is expected to reduce copper solubility by approximately 40 to 90 percent. To reduce Auburn's 90th percentile copper level from 1.57 mg/L to a level less than the action level of 1.3 mg/L, Auburn needs to treat the system to reduce at-the-tap monitoring results by at least 17 percent. Theoretical calculations indicate that the 90th percentile copper level can be reduced below the action level of 1.3 mg/L by increasing the pH in the Auburn system to approximately 7.0.

☐ At-the-tap monitoring conducted by Seattle (Chapman et al., 1989) indicate a 50 percent reduction in copper for samples collected before and after a pH increase from 7.2 to 8.2. Based on theory, copper solubility is calculated to be reduced by approximately 96 percent by increasing the pH in Seattle water from 7.2 to 8.2. Theoretical estimates of the reduction in copper solubility are approximately two times greater that at-the-tap monitoring results. Based on this comparison, a pH increase in Auburn water from 6.3-6.5 to 7.0 is expected to reduce the at-the-tap 90th percentile copper concentration by approximately 20 to 45 percent (rather than 40 to 90 percent based on theory alone). Thus, there is a high likelihood that the moderate pH increase to 7.0 will reduce Auburn's 90th percentile copper concentration below the action level of 1.3 mg/L. If not, it is nearly certain that a pH increase to 7.5 will be effective.

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Section 8
Recommended Treatment and Implementation Program

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Auburn can be considered optimized for copper corrosion control in two ways. One way is to demonstrate that the 90th percentile copper concentration is less than or equal to the action level of 1.3 mg/L for two consecutive monitoring periods. The second way is to apply the most reasonable treatment within regulatory and functional constraints of the system. Auburn did not meet the criterion of the first definition based on initial monitoring for the LCR, but Auburn likely can meet this first criterion by implementing the recommended corrosion control treatment strategy for the system. In the unlikely event that Auburn exceeds the copper action level after implementing the recommended strategy, Auburn will meet the second definition of optimization by applying the most reasonable corrosion control treatment to the Auburn system.

8.1 Target Water Quality Conditions

The recommended corrosion control treatment strategy for the Auburn water system is summarized on Table 8-1 and described below. The strategy is to treat Coal Creek springs and Well 2 to increase the system-wide blended pH of Auburn water (exclusive of the Lakeland Hills service area) to pH 7.0, and possibly up to pH 7.5 if needed. At-the-tap water quality data collected during initial monitoring for the LCR indicate that Auburn did not exceed the action level for lead, but Auburn barely exceeded the action level for copper (90th percentiles for copper were 1.57 and 1.5 mg/L). Source water quality data indicate that Auburn sources exhibit pH values ranging from 6.3 to 6.8. Distribution water quality samples indicate that Auburn exhibited a system-wide pH ranging from 6.4 to 6.6. The low pH characteristic of Auburn water likely is the cause of copper corrosion in the Auburn system.

8.1.1 Zone of Influence

Annual average flows reported for the Auburn system during initial monitoring for the LCR (1992-93) are summarized on Table 8-2. Also included on Table 8-2 are annual average flows for 1994 and forecast flows for the year 2010. Flows for 1992-93 indicate that the greatest fraction of total flow for the Auburn system was produced by Coal Creek springs, followed by Well 1, Well 4, and Well 2. For 1994, the greatest fraction of total flow was produced by Coal Creek springs, followed by Well 2, and then

Table 8-1
Auburn Water System
Recommended Source Water Treatment and Rational

Source	DOH Source ID #	Percentage of System Flow		Is Corrosion Control Treatment Recommended?	Rational
		1994	2010		
Coal Creek Springs	S01	54	28	yes	Water from Coal Creek springs serves the southern portion of the Auburn service area. Increase the pH at the source from 6.5 to 7.5.
West Hill Springs	S02	9	5	no	Water from West Hill springs is blended into the northwest service area and typically represents less than 10 percent of the total flow. Corrosion control treatment is not considered necessary for this source.
Well 1	S03	14	7	Possibly in Future	Water from Well 1 is pumped into the central portion of the Auburn service area. If necessary, corrosion control treatment may be installed for this well after the year 2000.
Well 2	S04	22	23	yes	Water from Well 2 serves the northern portion of the Auburn service area. Increase the pH at the source from 6.4 to 7.5.
Wells 3A and 3B	S04/S05	0	0	no	Water from Wells 3A and 3B exhibits naturally high levels of iron and manganese. Wells are used as supplemental supplies, on an emergency basis only. No corrosion control treatment is planned for these wells.
Well 4	S06	0	22	no	Water from Well 4 is blended with water from Coal Creek springs in a tank at the Coal Creek springs pump station. Dedicated corrosion control treatment facilities for this well are not considered necessary.
Wells 5 and 5A	S07/S09	1	1	no	Wells are used to serve the Lakeland Hills area exclusively. Initial monitoring results suggest that the 90th percentile lead and copper levels for the Lakeland Hills service area were below the action levels of the LCR. Corrosion control treatment is not considered necessary for the Lakeland Hills area. Additional at-the-tap monitoring will be conducted to confirm initial monitoring results.
Future Sources (Wells 6 and 7)	-	0	14	To be Determined	Water from future wells is expected to be similar to existing sources and not likely to impact Auburn's selection of a type of corrosion control treatment. If necessary, corrosion control treatment may be installed after the year 2000.

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Well 1. For the year 2010, the greatest production is forecast from Coal Creek springs, followed by Well 2 and Well 4. For all of these scenarios, Coal Creek springs represents the greatest proportion of flow, approximately 54 percent today and 28 percent in the year 2010. Well 2 represents 22 to 23 percent of total flow through the year 2010. Together, Coal Creek springs and Well 2 represent 76 percent of total flow today and 51 percent in the year 2010.

Table 8-2
Auburn Water System
Historical and Forecast Flow for Auburn Sources

	1992–1993		1994		2010	
Source	**MGD**	**%**	**MGD**	**%**	**MGD**	**%**
Coal Creek Springs	3.5	50	4.1	54	4.1	28
West Hill Springs	0	0	0.7	9	0.7	5
Well 1	1.7	25	1.0	14	1.0	7
Well 2	0.7	10	1.7	22	3.4	23
Wells 3A and 3B	0	0	0	0	0	0
Well 4	1.0	14	0	0	3.2	22
Wells 5 and 5A	0.1	1	0.1	1	0.1	1
Future Sources (Wells 6 and 7)	–	–	–	–	2.0	14
Total	**7**	**100**	**7.6**	**100**	**14.5**	**100**

Hydraulic modeling was conducted by Auburn to evaluate the zone of influence of each of Auburn's sources in the distribution system. The CYBERNET model for Auburn was developed previously by Auburn (1994). For this desktop evaluation, the hydraulic model was operated at peak summer flow for all of Auburn's sources based on production data for 1994.

The hydraulic modeling results for Coal Creek springs and Well 2 are shown on Exhibit 8-1. These two sources were selected because they represent an estimated 76 percent of the system flow in 1994. The shaded areas on Exhibit 8-1 represent areas of the distribution system which consist of 20 percent or more water from Coal Creek springs or Well 2. These modeling results demonstrate that the zone of influence of Coal Creek springs covers the southern portion of the Auburn system and the zone of influence of Well 2 covers the northern portion.

Residual chlorine concentrations measured in the Auburn distribution system were evaluated and compared to the results of hydraulic modeling to verify the zone of influence of the Coal Creek springs and Well 2. Sampling locations and chlorine residuals collected during 1992, 1993 and 1995 are shown on Exhibit 8-2. During these sampling periods, chlorine was added at

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Exhibit 8-1
AuburnWater System
Zone of Influence Map for Coal Creek Springs and Well 2

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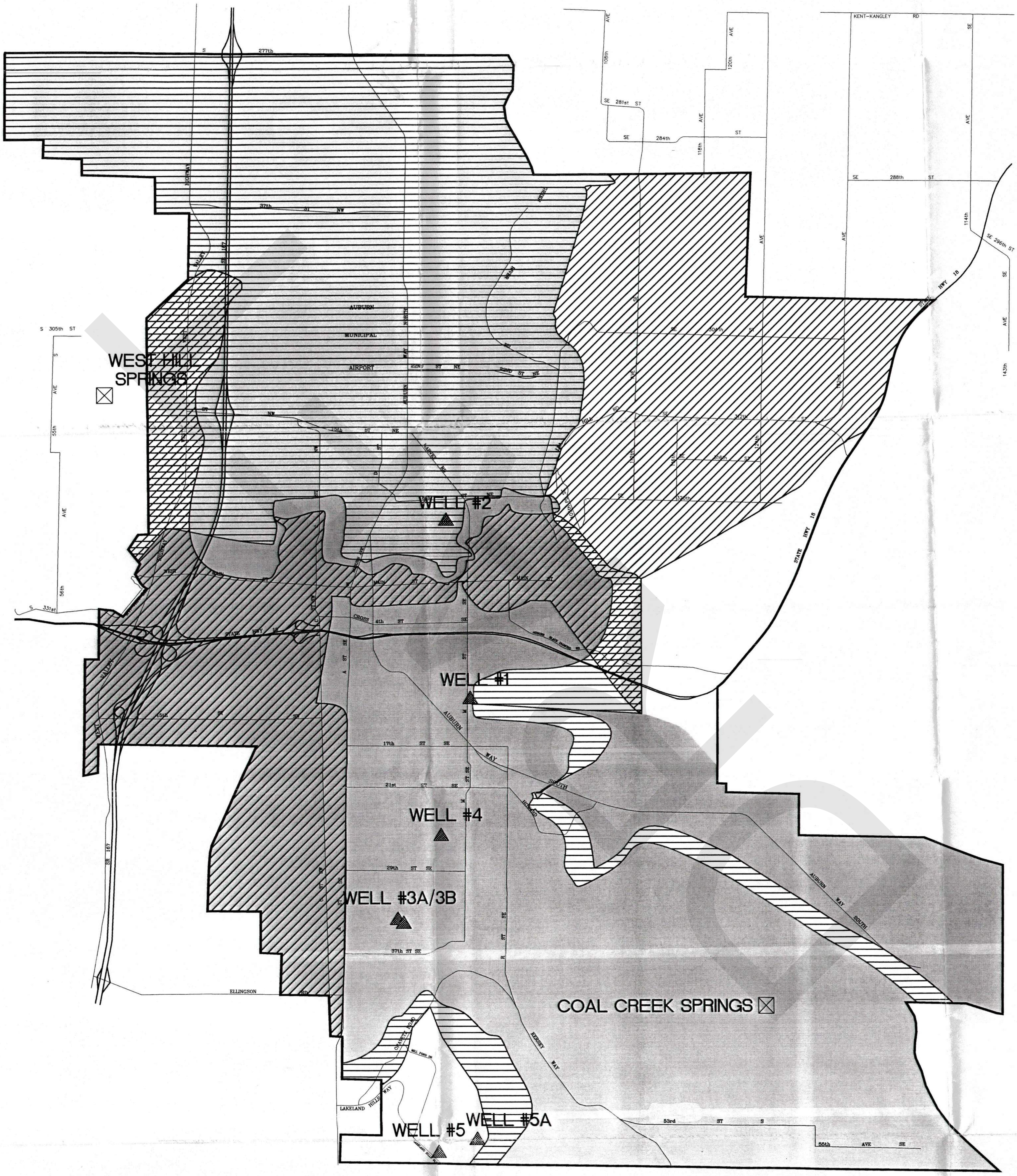

L E G E N D

- ▒ MORE THAN 20% FROM COAL CREEK SPRINGS
- ▤ 0% TO 20% FROM COAL CREEK SPRINGS
- ░ MORE THAN 20% FROM WELL # 2
- ▨ 0% TO 20% FROM WELL # 2
- WATER SERVICE AREA BOUNDARY

N

CITY OF AUBURN
PUBLIC WORKS DEPARTMENT
Geographic Information System

CITY OF AUBURN
SOURCE FRACTION
1994

MAY '95

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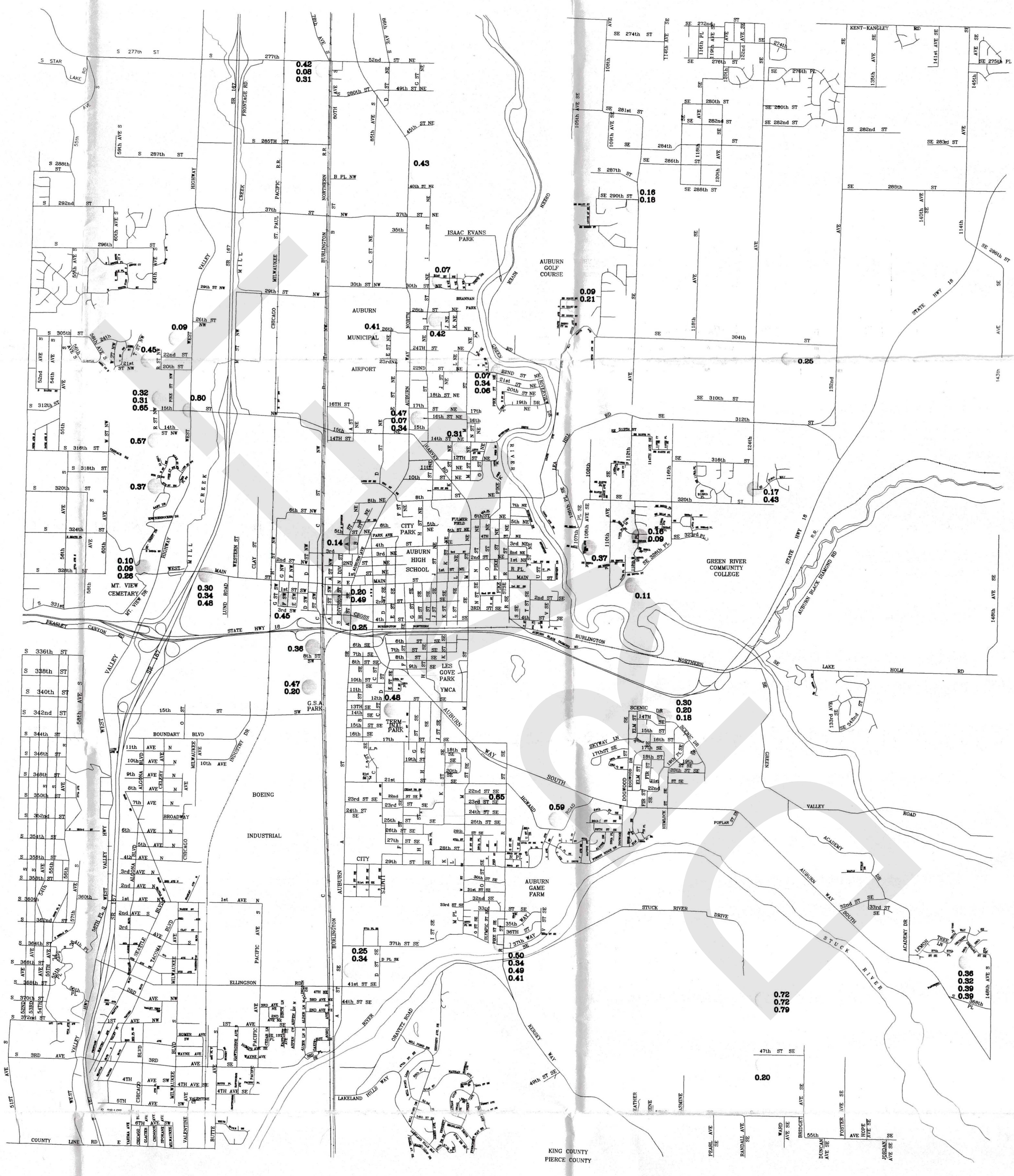
Exhibit 8-2
AuburnWater System
Map of Chlorine Residuals
Reported in 1992, 1993, and 1995



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CORROSION CONTROL STUDY

GENERAL LOCATION
OF SAMPLE

MAY '95

Coal Creek springs and West Hill springs. Data on Exhibit 8-2 indicate an area in the northwestern portion of the Auburn system with somewhat elevated chlorine residuals, attributed to disinfection treatment at West Hill springs. In addition, these data indicate higher chlorine residuals in the southern portion of the Auburn service area, consistent with the zone of influence predicted by the hydraulic model. Chlorine residuals also are observed throughout the Auburn service area, indicating that treatment reaches the outer extremities of the Auburn system.

Based on hydraulic modeling and chlorine residual data, corrosion control treatment applied to Coal Creek springs and Well 2 would be expected to affect the vast majority of the Auburn system. However, some small, local areas in the immediate vicinity of untreated sources may not be blended and therefore may not be affected by corrosion control treatment. These local areas will need to be monitored during implementation of corrosion control treatment to evaluate the impact at-the-tap.

8.1.2 System-Wide Effects of Treatment

Exhibit 8-3 shows a plot of the system-wide blended pH for the Auburn system as a function of the percentage of total sources treated. Included on this plot are curves based on flow data for 1994 and forecast flow for the year 2010. Treated sources (as a percentage of total flow) refers to Auburn sources which have been raised to pH 7.5. These curves demonstrate that when approximately 76 percent of the Auburn sources are treated at the source to pH 7.5, the system-wide blended pH can be elevated to approximately pH 7.0. This system-wide blended pH of 7.0 is expected to result in at-the-tap copper concentrations below the action level of 1.3 mg/L. The spreadsheet calculations used to prepare Exhibit 8-3 are included in Appendix D.

For the two curves shown on Exhibit 8-3, the system-wide blended pH for 1994 was observed to be different than the system-wide blended pH for the year 2010. This difference in system-wide blended pH is attributed to the different flows for Auburn sources during the two years. For example, in the year 1994, the pH-adjusted sources (Coal Creek springs and Well 2) represent 76 percent of the total flow whereas the same two pH-adjusted sources represent 52 percent of the total flow in the year 2010. Auburn is aware of the possible impacts that changes in flows may have on pH in the system and is prepared to monitor these effects and modify corrosion control treatment accordingly.

Data and information from theory and analogous systems suggest that a moderate increase in water pH to approximately 7.0 can produce a significant reduction in the average rate of copper corrosion. By increasing Auburn source water pH to a system-wide blended pH of 7.0, overall copper corrosion in the Auburn system will

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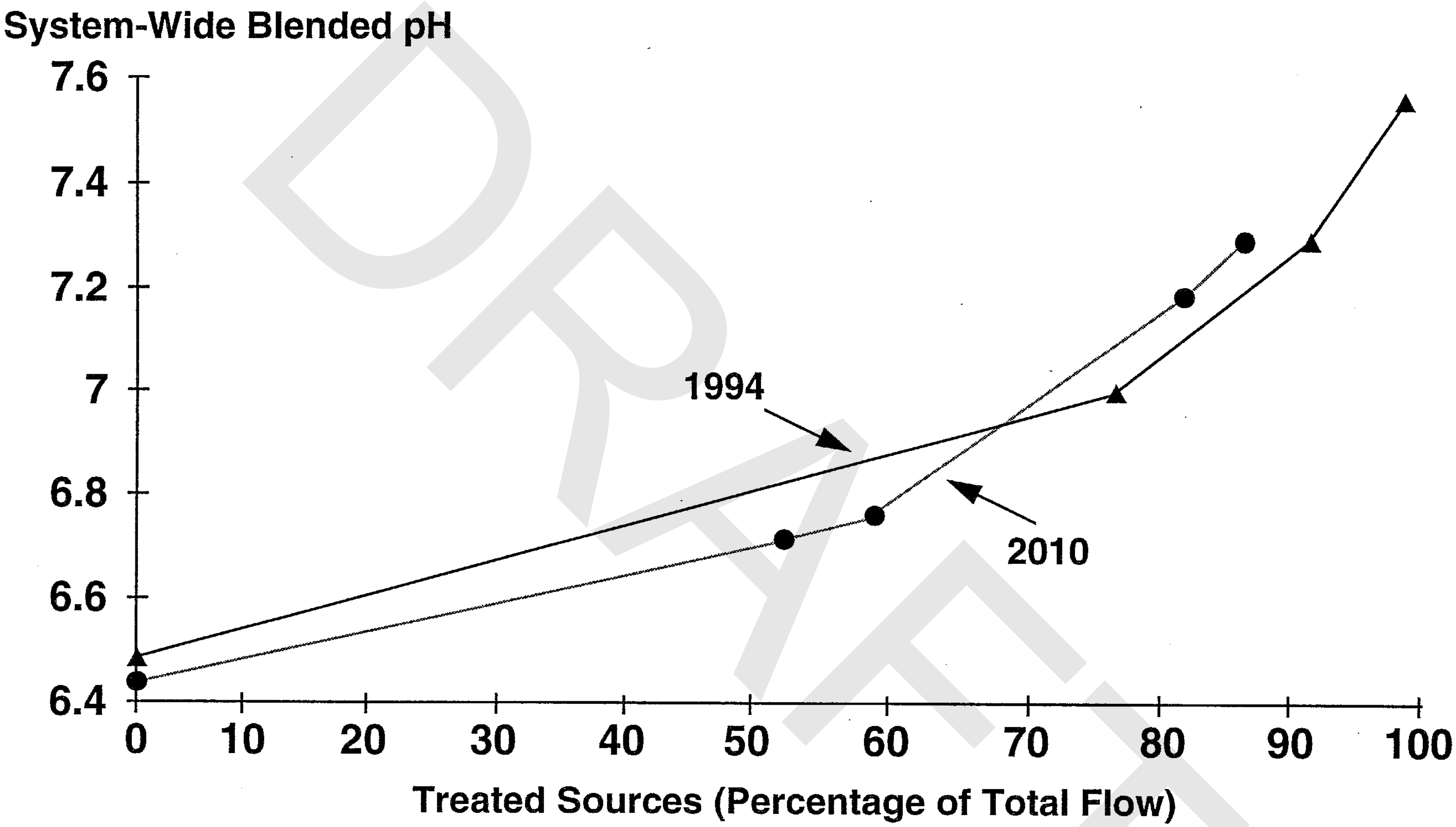

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Exhibit 8-3
Auburn Water System
System-Wide Blended pH vs. Treated Sources

be reduced and the 90th percentile copper concentration is expected to be less than the action level of the LCR. If pH adjustment to a system-wide blended pH of 7.0 is not sufficient to reduce the 90th percentile copper concentration, then Auburn will evaluate alternative operational strategies to reduce overall corrosion and the need for additional treatment facilities.

pH adjustment for Auburn sources could be accomplished by adding caustic soda (NaOH), by aeration, or by some other chemical treatment. The advantages and disadvantages of various pH adjustment alternatives need to be investigated as part of predesign, before designing the final treatment technology.

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8.2 Implementation Program

The overall schedule for implementation will be driven by the Lead and Copper Rule deadline of January 1, 1998 for medium systems to complete installation of corrosion control treatment facilities. To meet this deadline, certain issues need to be addressed as Auburn moves forward with implementation of pH adjustment for corrosion control.

8.2.1 Preliminary Design, Design and Construction Schedule

Regulatory milestones will be the driving force behind the schedule for preliminary design, final design and construction of Auburn's corrosion control treatment facilities. Assuming 18 to 24 months to complete this project, preliminary design should commence in January 1996 to meet the start-up deadline of January 1998. Issues that need to be addressed include the selection of a pH adjustment approach and the determination of the location of corrosion control treatment facilities. These issues are discussed below.

pH Adjustment Approach

A solid chemical feed system is not the most appropriate pH adjustment approach for a system such as Auburn. Lime and soda ash feed systems can be labor intensive, expensive, and typically are used for large-scale operations. A liquid feed system using caustic soda may be suitable for Auburn. Alternatively, pH adjustment may be achieved by aeration technology as demonstrated by Vancouver, Washington.

To determine the most practical and cost effective pH adjustment system for Auburn, pH titrations using caustic soda should be conducted with Auburn water to determine the amount of chemical necessary to reach pH 7.5 for Coal Creek springs and Well 2. Pilot studies also should be conducted to evaluate the applicability of stripping CO_2 to raise the water pH.

Site Evaluation

A study needs to be conducted to evaluate the feasibility of treating multiple sources at central locations, including the planned pump station for the Lea Hill pressure zone. The location of all treatment facilities should allow for possible future compliance with Ct requirements of the GWDR and SWTR, and possible future requirements of the Radon Rule.

8.2.2 Monitoring

Water quality monitoring will be conducted to evaluate the need for corrosion control treatment in the Lakeland Hills area and the effects of corrosion control on customers near untreated sources.

Lakeland Hills Monitoring

Samples will be collected from a minimum of 20 sites in the Lakeland Hills area to establish statistically representative 90th percentile levels for lead and copper (based on small systems serving from 501 to 3,300 people per the LCR). The results of these analyses will be used to confirm that Wells 5 and 5A, which serve the Lakeland Hills area, do not need corrosion control treatment.

Monitoring Near Untreated Sources

Samples will be collected from a minimum of 5 sites (based on small water systems serving up to 100 people per the LCR) in the areas near Auburn sources which are not treated for corrosion control. Monitoring will be conducted near the entry points for West Hill springs, Well 1 and Well 4. Wells 3A and 3B will not be monitored because they are supplemental sources used for emergency purposes only. Results will be used to evaluate the effectiveness of corrosion control treatment in areas near untreated sources.

8.2.3 Start-Up Approach

Water distribution systems are delicate in the balance they maintain between physical conditions (such as flow rates and direction), chemical parameters (such as pH and chlorine residuals), and microbiological organisms (such as coliform and heterotrophic plate counts). Customer confidence and compliance with health regulations are at stake. Changes that potentially can disrupt the delicate balance of the system must be executed carefully and deliberately. In order to implement corrosion control treatment and minimize the disruptive effects of a pH increase on the

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Auburn system, the corrosion control strategy should be conducted as a phased approach.

Exhibit 8-4 illustrates the recommended staged implementation strategy for corrosion control treatment in the Auburn water system. The first step of the corrosion control strategy will involve a pH increase for water from Coal Creek springs and Well 2 to pH 7.5 to attain a system-wide blended pH of 7.0. After a period of equilibration, tap water samples will be collected from the same sites sampled during base line monitoring to assess the levels of lead and copper in the pH-adjusted water. If results are favorable, then treatment will continue at Coal Creek springs and Well 2 for three to six months, followed by additional tap water monitoring during the first six-month period of 1998. Treatment will be considered optimal when the following criteria are met:

- ☐ Copper levels are reduced and maintained below the action level of 1.3 mg/L;
- ☐ No significant evidence of adverse impacts of the treatment on bacteriological quality in the distribution system;
- ☐ No significant adverse impacts of the treatment on domestic customer satisfaction (e.g., red water due to disturbances in unlined cast iron, or black water attributed to precipitation of source water manganese);
- ☐ No significant adverse impact on commercial and industrial customers, health care facilities, and wastewater facilities; and

If follow up monitoring indicate that the 90th percentile action levels are not met, then Auburn will evaluate alternative operations to reduce overall corrosion and the need to add treatment facilities at Well 1 (Stage 2). Additional monitoring will be conducted and results will be compared to the criteria listed above. Although not likely to be required, treatment could be modified further to construct treatment facilities for Well 4 and West Hill springs, if needed.

8.3 Estimated Costs

Capital, chemical, and operation and maintenance (O&M) cost estimates were prepared for two treatment scenarios for corrosion control treatment in the Auburn system: (1) pH increase to 7.5 at the source to attain a system-wide blended pH of 7.0 using caustic soda (NaOH); and (2) pH increase to 7.5 at the source to attain a system-wide blended pH of 7.0 using aeration. Cost estimates are included for Coal Creek springs, Well 1 and Well 2 and treatment is assumed to be operated

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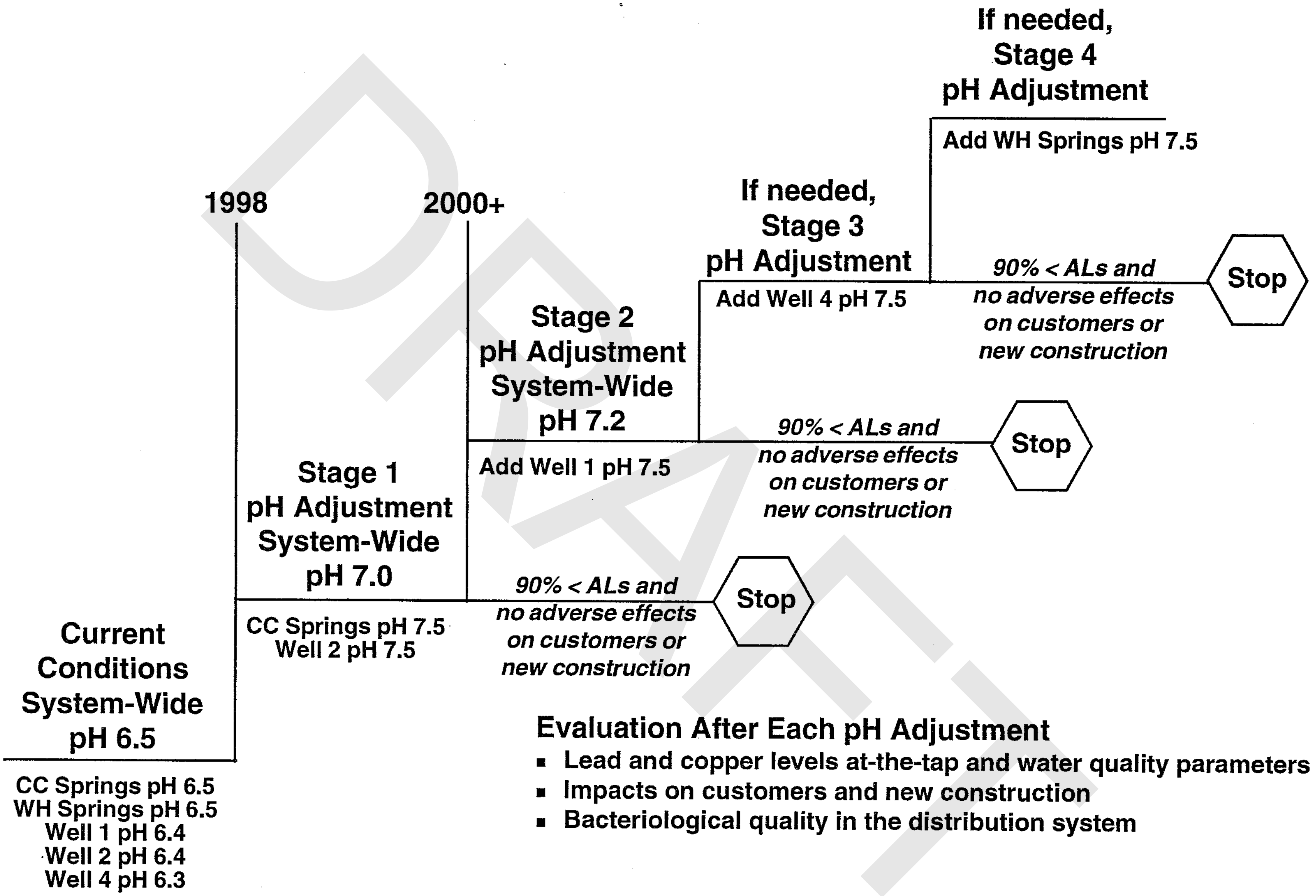

Evaluation After Each pH Adjustment

- Lead and copper levels at-the-tap and water quality parameters
- Impacts on customers and new construction
- Bacteriological quality in the distribution system

Exhibit 8-4
Auburn Water System
Recommended Implementation of Corrosion Control Strategy

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continuously throughout the year. These cost estimates are conceptual and, as such, generally fall within plus or minus 30 to 40 percent of final costs.

Construction and O&M costs are based on cost curves provided by the USEPA (1979) and inflated to current dollars based on the ENR CCI of 2851 for the nation in April 1978 and 5799 for Seattle in February 1995. Recent experiences with construction of similar treatment facilities in the Puget Sound area also were considered. The USEPA cost curves can be used to estimate the relative economics of alternative treatment systems and for the preliminary evaluation of general cost levels to be expected for a proposed project. Construction cost curves were developed by USEPA using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. Construction costs include manufactured equipment, labor, pipe and valves, electrical equipment and instrumentation, housing, and general contractor's overhead and profit.

For the caustic soda feed system, the construction cost estimates were based on the following assumptions: use of 50 percent sodium hydroxide solution delivered premixed by bulk transport; 20 days of storage in FRP tanks; storage tanks are located indoors; and dual head metering pumps plus a standby pump. Construction cost estimates do not include site specific costs such as acquisition of land, permitting, costs for providing utilities to the site, offsite improvements, enhanced architectural design and landscaping, or other site specific considerations. O&M costs include process energy and building energy based on $0.06 per kw-hr, maintenance materials, and labor at $24 per hour.

For the purpose of this evaluation, construction costs were based on peak flow rates and O&M costs were based on straight-line interpolation of annual average flows from 1995 through the year 2010 as shown in Table 8-3.

Table 8-3
Auburn Water System
Corrosion Control Study
Assumptions for Estimating Treatment Costs

Source	Peak Flow (MGD)	Annual Average Flow (MGD)	
		1994	2010
Coal Creek Springs	4.1	4.1	4.1
Well 2	3.4	1.7	3.4
Well 1	1.0	1.0	1.0

The total construction cost estimates include 25 percent contingency plus 32 percent of construction + contingency for engineering, legal, and administrative fees. Chemical cost estimates represent chemical dosage requirements for pH increases to 7.5 for each source based on the Rothberg, Tamburini and Winsor Model (1994). O&M and chemical cost estimates include 25 percent for contingencies. Conceptual diagrams of caustic feed and aeration treatment facilities that may be constructed for Auburn are included in Appendix E.

Cost estimates associated with caustic soda feed and aeration treatment for the Auburn system are summarized on Table 8-4. For Stage 1 of Auburn's corrosion control treatment strategy, the capital cost to construct caustic soda feed facilities for Coal Creek springs and Well 2 is estimated to be approximately $413,000, and could be as much as $578,000. The total present worth (15 year return) to operate treatment at the two sources is estimated to be $5,264,000. If aeration technology is selected for pH adjustment in the Auburn system, then the capital cost to construct treatment facilities is estimated to be approximately $2,056,000 and could be as much as $2,878,000. The total present worth (15 year return) is estimated to be $5,086,000. The higher annual O&M costs for aeration treatment at Well 2 compared to Coal Creek springs is attributed to the need to install and operate disinfection treatment, which currently is operational at Coal Creek springs.

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Table 8-4
Auburn Water System
Estimated Costs for Corrosion Control Treatment

Stage	Treatment Site	Capital Cost[a]	Annual O&M Cost[b]		Total Present Worth[d]
		1997[c]	1995[c]	2010[c]	(15 yr return)
1	Coal Creek Springs				
	Caustic Soda	$165,000	$194,000	$194,000	$2,286,000
	Aeration	$1,178,000	$45,000	$45,000	$1,628,000
1	Well 2				
	Caustic Soda	$248,000	$173,000	$334,000	$2,978,000
	Aeration	$878,000	$168,000	$315,000	$3,458,000
1	**Stage 1 Total**				
	Caustic Soda	**$413,000**	**$367,000**	**$528,000**	**$5,264,000**
	Aeration	**$2,056,000**	**$213,000**	**$360,000**	**$5,086,000**
2	Well 1				
	Caustic Soda	$165,000	$81,000	$81,000	$1,048,000
	Aeration	$492,000	$100,000	$100,000	$1,575,000
1 & 2	**Stages 1&2 Total**				
	Caustic Soda	**$578,000**	**$448,000**	**$609,000**	**$6,312,000**
	Aeration	**$2,548,000**	**$313,000**	**$460,000**	**$6,661,000**

a *Includes construction costs, 25 percent contingencies, and 32 percent for engineering, legal, and administrative fees.*
b *Includes chemicals, process power, building power, labor, repairs, and 25 percent contingency.*
c *Costs are shown in 1995 dollars; the date represents the year the costs are expected to be incurred.*
d *Present worth cost estimates are shown in 1995 dollars and are based on an inflation rate of 4 percent and a discount rate of 6 percent. Capital costs are inflated and incurred in the year 1997. O&M costs are inflated and begin January 1, 1998.*

For Stage 2, the capital cost to construct caustic soda feed facilities for Well 1 is estimated to be approximately $165,000 and the total present worth (15 year return) is estimated to be $1,048,000. For aeration technology, the capital cost is estimated to be $492,000 with a total present worth (15 year return) of $1,575,000. Additional construction and chemical costs are included in the aeration costs estimates for disinfection treatment.

As mentioned previously, total capital cost estimates for caustic soda feed systems are based on the use and storage of 50 percent sodium hydroxide solution. If Auburn decides to implement caustic soda treatment using 25 percent sodium hydroxide solution, then the total capital costs could increase by as much as 50 percent to construct larger buildings and provide additional storage capacity. For this scenario, the total capital cost to provide treatment for Coal Creek springs and Well 2 is estimated to be $620,000 and could be as much as $868,000. Chemical and O&M costs also may be higher if a 25 percent sodium hydroxide solution is used.

8.4 DOH Approval and Monitoring Requirements

On May 25, 1995, representatives of the City of Auburn and Economic and Engineering Services, Inc. met with representatives of Washington State Department of Health to discuss the recommended strategy for corrosion control treatment for the Auburn water system. As a result of the meeting, this report was revised to include additional documentation supporting the system-wide pH goal of 7.0 for copper corrosion control in the Auburn system, additional monitoring for the Lakeland Hills service area and near untreated sources, and the possible need for a bilateral agreement between the City of Auburn and DOH.

The Lead and Copper Rule requires that medium systems complete their corrosion control studies and recommend a treatment method to the State (in this case DOH) by July 1, 1995. This report complies with this requirement. DOH has six months (until January 1, 1996) to review the recommendation and to designate a corrosion control treatment, which may or may not be the same as that recommended by Auburn. Auburn then has two years to design, construct and startup designated corrosion control treatment prior to the January 1, 1998 compliance deadline.

Auburn will be required to complete one year of follow-up monitoring after treatment installation to determine the performance of corrosion control. Following another six month review period, DOH will designate the water quality parameters (WQPs) required for LCR compliance by July 1, 1999. It is presumed that DOH and Auburn would participate jointly in the WQP designation process.

The Lead and Copper Rule specifies monitoring requirements for a public water system after corrosion control treatment facilities have been installed and after the State specifies water quality parameter operating ranges. When pH adjustment is identified as the optimal corrosion control treatment, pH must be measured at a minimum of once every two weeks at the entry point to the distribution system, and

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two samples must be collected every six months from at least 10 distribution system sites. Systems such as Auburn that remain within the State-specified water quality parameter ranges for two consecutive six-month monitoring periods may reduce the number of samples from 10 distribution system sites to 5 sites. After three years of maintaining the State-specified water quality parameter ranges, monitoring frequency may be reduced to once per year. There is no reduced monitoring allowed for samples collected at the point of entry to the distribution system.

To determine whether tap copper levels are above or below the action level, Auburn will be required to conduct two consecutive six-month monitoring rounds following installation of corrosion control treatment. The first round will begin January 1998 and includes lead and copper tap sampling at a minimum of 60 Tier 1 sites. The second round occurs between July and December 1998 and also requires a minimum of 60 Tier 1 sites to be sampled for lead and copper. Between January and June 1999, the State will specify the WQPs for Auburn's optimal corrosion control treatment. After the state determines WQPs for Auburn, two six-month monitoring periods will follow for the same Tier 1 sites. If Auburn meets the lead and copper action levels or maintains the DOH-specified optimal corrosion control treatment for two consecutive 6-month periods, then tap water sampling may be reduced to annually at 30 Tier 1 sites. Medium-size systems that maintain State-specified WQPs for six consecutive 6-month monitoring periods (3 years) may reduce lead and copper tap water sampling to 30 Tier 1 sites once every 3 years.

8.5 Summary

The recommended corrosion control treatment strategy for the Auburn water system is to increase the system-wide blended pH of the Auburn system to 7.0. Two issues need to be evaluated as part of the predesign and design phase: (1) select appropriate pH adjustment treatment technologies and (2) select appropriate treatment sites. Once the pH adjustment technologies are selected, a more detailed cost summary can be developed. Site evaluations should include an assessment of the feasibility of centralized treatment facilities for Auburn sources (e.g. future pump station at Lea Hill).

Exhibit 8-5 is a schedule for Auburn to comply with requirements of the Lead and Copper Rule. Upon approval by DOH, Auburn should begin engineering predesign, siting, design, and construction of treatment facilities for Coal Creek springs and Well 2 and complete construction for start-up by January 1, 1998. After start-up, Auburn will operate three to six months at a system-wide blended pH of 7.0. If monitoring results are favorable, then Auburn will continue operating at a system-wide blended pH of 7.0. If monitoring results are not favorable, then Auburn will evaluate alternative operations to reduce overall corrosion and the need to proceed with Stage 2, which may include construction of treatment facilities for Well 1.

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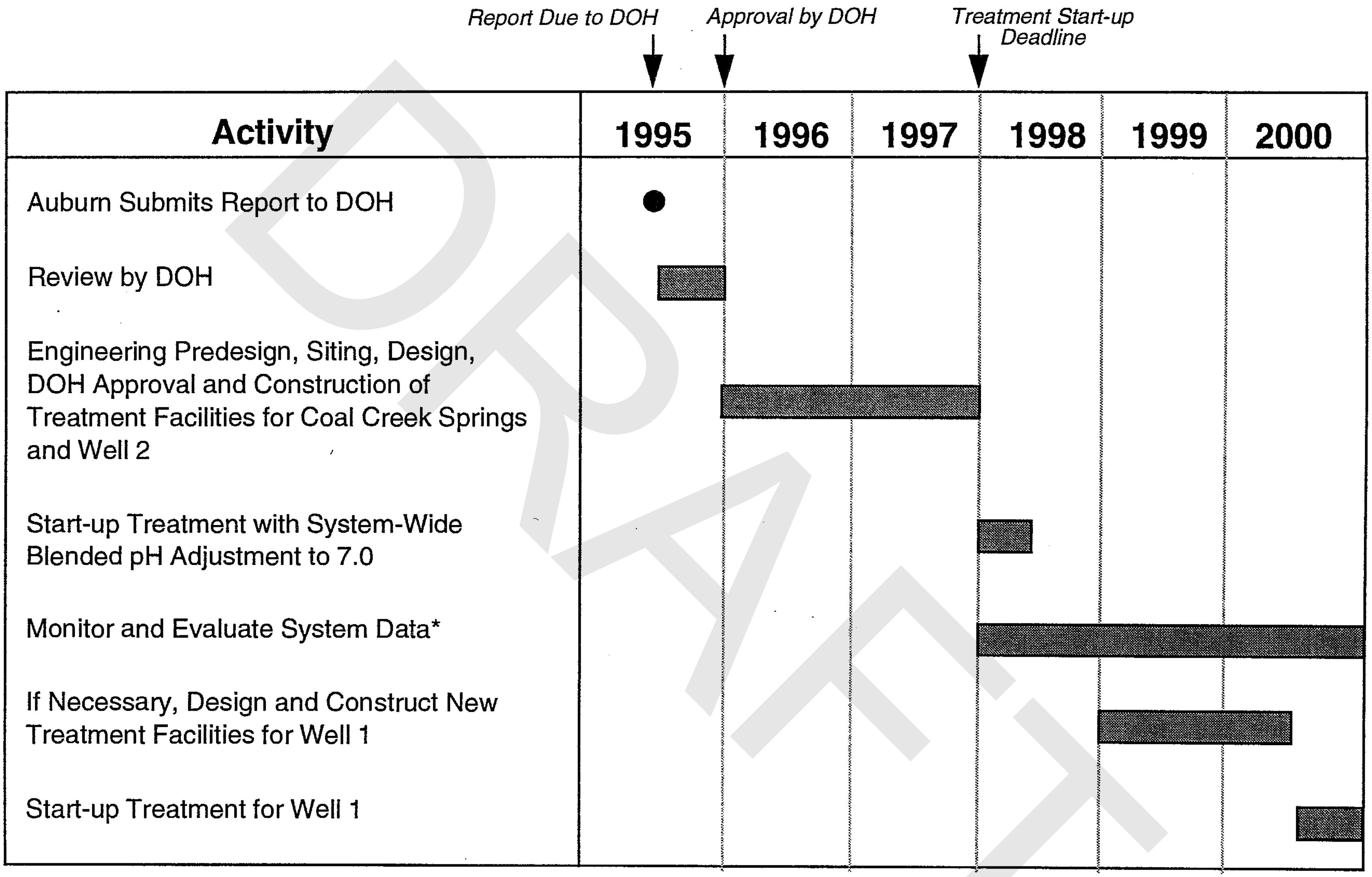

* *Monitoring results will determine need for additional corrosion control treatment. If Auburn remains below the action levels after installation of treatment, DOH may reduce monitoring frequency requirements.*

Exhibit 8-5
Auburn Water System
Lead and Copper Rule—Compliance Schedule

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Appendix A
Monitoring Period Data Summaries

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Table A-1
Auburn Water System
Monitoring Period Data Summary
First-Draw Tap Samples (Lead and Copper) Collected Between 7/92 and 12/92

Lead (Pb)		Copper (Cu)	
Min. Concentration 0.002 mg/L	90th Percentile 0.006 mg/L	Min. Concentration 0.02 mg/L	90th Percentile 1.57 mg/L
Max. Concentration 0.015 mg/L	% of Samples Exceed. AL 0%	Max. Concentration 5.85 mg/L	% of Samples Exceed. AL 15%

WATER QUALITY PARAMETER AND SOURCE LEAD AND COPPER SAMPLES

POINT OF ENTRY (POE) (After Treatment)									DISTRIBUTION SYSTEM	
POE Description	**A**		**B**		**C**		**D**		Sampled Between 9/29/92 & 10/26/92	
System's name for the POE	**Well #1**		**Well #2**		**Well #3A**		**Well #3B**			
All DOH Source ID #s connected to the POE	**SO3**		**SO4**		**SO5**		**SO8**			
MAX. SOURCE LEAD, mg/L / Date	<0.002 / 10-26-92		<0.002 / 9-29-92		<0.002 / 10-26-92		<0.002 / 9-29-92		Total Number of Samples: 20	
MAX. SOURCE COPPER, mg/L / Date	0.06 / 10-26-92		0.15 / 9-29-92		0.05 / 10-26-92		0.15 / 9-29-92			
WQP Samples	1	**2**	1	**2**	1	**2**	1	**2**	**Minimum Value**	**Maximum Value**
Date of WQP sample collection	9-29-92	10-26-92	9-29-92	10-26-92	9-29-92	10-26-92	9-29-92	10-26-92		
Sources operating when sample collected										
pH (should be field measured)	6.3	6.3	6.3	6.3	7.4	6.9	7.4	6.8	6.2	6.5
Temperature, °C (field measured)	11.1	11.1	11.7	11.1	11.7	10.0	11.7	10.0	13.3	19.4
Alkalinity, mg/L as $CaCO_3$	67	61	97	100	*	100	76	105	46	91
Calcium, mg/L as $CaCO_3$	61	61	70	65	*	42	42	64	36	89
Conductivity, μmhos/cm at 25°C	185	184	239	235	*	194	196	200	122	223
Orthophosphate, mg/L as PO_4[1]										
Silicate, mg/L as SiO_2[1]										
(OTHER)[2]										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										

[1] Only required if PO_4 or SiO_2 is applied in the treatment process.

[2] See ___ for list of other parameters that may be useful in examination of corrosion control options.

To convert from:	**to:**	
Phosphate, mg/L as P	mg/L as PO_4	multiply by 3
Calcium, mg/L as Ca	mg/L as $Ca\ CO_3$	multiple by 2.5
Temperature in °F	°C	subtract 32, then divide by 1.8
Alkalinity in meq/L	mg/L as $CaCO_3$	multiply by 50

* *Lost sample at laboratory. Wells 3A and 3B are approximately 60 feet a part and pumped from the same depth.*

Table A-1 (continued)
Auburn Water System
Monitoring Period Data Summary
First-Draw Tap Samples (Lead and Copper) Collected Between 7/92 and 12/92

Lead (Pb)		Copper (Cu)	
Min. Concentration _____ mg/L	90th Percentile _____ mg/L	Min. Concentration _____ mg/L	90th Percentile _____ mg/L
Max. Concentration _____ mg/L	% of Samples Exceed. AL _____%	Max. Concentration _____ mg/L	% of Samples Exceed. AL _____%

WATER QUALITY PARAMETER AND SOURCE LEAD AND COPPER SAMPLES

	POINT OF ENTRY (POE) (After Treatment)								DISTRIBUTION SYSTEM	
POE Description	**E**		**F**		**G**		**H**		Sampled Between _________ & _________	
System's name for the POE	**Well #4**		**Well #5**		**Coal Creek Springs**		**Hidden Valley**			
All DOH Source ID #s connected to the POE	**SO6**		**SO7**		**SO1**		**SO1**			
MAX. SOURCE LEAD, mg/L / Date	<0.002 / 10-26-92		<0.002 / 10-26-92		<0.002 / 10-26-92		<0.004 / 9-29-92		Total Number of Samples: _________	
MAX. SOURCE COPPER, mg/L / Date	<0.02 / 10-26-92		<0.02 / 10-26-92		<0.02 / 10-26-92		<0.02 / 9-29-92			
WQP Samples	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**Minimum Value**	**Maximum Value**
Date of WQP sample collection	9-29-92	10-26-92	9-29-92	10-26-92	9-29-92	10-26-92	9-29-92	10-26-92		
Sources operating when sample collected										
pH (should be field measured)	6.2	6.2	6.9	6.5	6.4	6.4	6.8	6.4		
Temperature, °C (field measured)	10.6	10.6	9.4	9.4	11.1	11.1	10.0	9.4		
Alkalinity, mg/L as $CaCO_3$	57	59	69	78	47	45	66	69		
Calcium, mg/L as $CaCO_3$	48	44	42	36	31	28	48	42		
Conductivity, μmhos/cm at 25°C	150	146	160	148	117	114	138	139		
Orthophosphate, mg/L as PO_4[1]										
Silicate, mg/L as SiO_2[1]										
(OTHER)[2]										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										

[1] Only required if PO_4 or SiO_2 is applied in the treatment process.

[2] See ___ for list of other parameters that may be useful in examination of corrosion control options.

To convert from:	**to:**	
Phosphate, mg/L as P	mg/L as PO_4	multiply by 3
Calcium, mg/L as Ca	mg/L as Ca CO_3	multiple by 2.5
Temperature in °F	°C	subtract 32, then divide by 1.8
Alkalinity in meq/L	mg/L as $CaCO_3$	multiply by 50

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Table A-2
Auburn Water System
Monitoring Period Data Summary
First-Draw Tap Samples (Lead and Copper) Collected Between 1/93 and 6/93

Lead (Pb)		Copper (Cu)	
Min. Concentration <0.002 mg/L	90th Percentile 0.006 mg/L	Min. Concentration <0.02 mg/L	90th Percentile 1.5 mg/L
Max. Concentration 0.013 mg/L	% of Samples Exceed. AL 0%	Max. Concentration 3.5 mg/L	% of Samples Exceed. AL 17%

WATER QUALITY PARAMETER AND SOURCE LEAD AND COPPER SAMPLES

	POINT OF ENTRY (POE) (After Treatment)								DISTRIBUTION SYSTEM	
POE Description	**A**		**B**		**C**		**D**		Sampled Between 4-29-93 & 5-27-93 Total Number of Samples: 20	
System's name for the POE	**Well #1**		**Well #2**		**Well #3A**		**Well #3B**			
All DOH Source ID #s connected to the POE	**SO3**		**SO4**		**SO5**		**SO8**			
MAX. SOURCE LEAD, mg/L / Date	<0.002 / 6-1-93		<0.02 / 4-29-93		0.005 / 4-29-93		<0.02 / 4-29-93			
MAX. SOURCE COPPER, mg/L / Date	0.02 / 6-1-93		<0.02 / 4-29-93		0.04 / 4-29-93		<0.02 / 4-29-93			
WQP Samples	1	2	1	2	1	2	1	2	**Minimum Value**	**Maximum Value**
Date of WQP sample collection	4-29-93	6-1-93	4-29-93	6-1-93	4-29-93	6-1-93	4-29-93	6-1-93		
Sources operating when sample collected										
pH (should be field measured)	6.53	6.48	6.68	6.60	6.1	7.12	6.3	7.18	6.33	7.5
Temperature, °C (field measured)	11.7	12.2	11.7	12.2	12.2	11.1	11.7	11.1	11.1	18.3
Alkalinity, mg/L as CaCO$_3$	66	62	91	92	88	94	100	102	44	86
Calcium, mg/L as CaCO$_3$	58	55	57	61	42	42	43	42	32	68
Conductivity, μmhos/cm at 25°C	173	170	213	218	173	181	177	189	103	197
Orthophosphate, mg/L as PO$_4$[1]										
Silicate, mg/L as SiO$_2$[1]										
(OTHER)[2]										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										

1 Only required if PO$_4$ or SiO$_2$ is applied in the treatment process.
2 See ___ for list of other parameters that may be useful in examination of corrosion control options.

To convert from:	**to:**	
Phosphate, mg/L as P	mg/L as PO$_4$	multiply by 3
Calcium, mg/L as Ca	mg/L as Ca CO$_3$	multiple by 2.5
Temperature in °F	°C	subtract 32, then divide by 1.8
Alkalinity in meq/L	mg/L as CaCO$_3$	multiply by 50

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Table A-2 (continued)
Auburn Water System
Monitoring Period Data Summary
First-Draw Tap Samples (Lead and Copper) Collected Between 1/93 and 6/93

Lead (Pb)		Copper (Cu)	
Min. Concentration _____ mg/L	90th Percentile _____ mg/L	Min. Concentration _____ mg/L	90th Percentile _____ mg/L
Max. Concentration _____ mg/L	% of Samples Exceed. AL _____%	Max. Concentration _____ mg/L	% of Samples Exceed. AL _____%

WATER QUALITY PARAMETER AND SOURCE LEAD AND COPPER SAMPLES

POINT OF ENTRY (POE) (After Treatment)									DISTRIBUTION SYSTEM	
POE Description	**E**		**F**		**G**		**H**		Sampled Between 4-29-93 & 5-27-93 Total Number of Samples: 20	
System's name for the POE	**Well #4**		**Well #5**		**Coal Creek Springs**		**Hidden Valley**			
All DOH Source ID #s connected to the POE	**SO6**		**SO7**		**SO1**		**SO1**			
MAX. SOURCE LEAD, mg/L / Date	<0.02 / 4-29-93		<0.02 / 4-29-93		<0.02 / 4-29-93		<0.02 / 4-29-93			
MAX. SOURCE COPPER, mg/L / Date	<0.02 / 4-29-93		<0.02 / 4-29-93		<0.02 / 4-29-93		<0.02 / 4-29-93			
WQP Samples	1	**2**	1	**2**	1	**2**	1	**2**	**Minimum Value**	**Maximum Value**
Date of WQP sample collection	4-29-93	6-1-93	4-29-93	6-1-93	4-29-93	6-1-93	4-29-93	6-1-93		
Sources operating when sample collected										
pH (should be field measured)	6.45	6.39	7.10	7.03	6.65	6.56	6.3	7.08		
Temperature, °C (field measured)	11.1	11.1	10.0	10.0	10.0	10.0	10.0	10.0		
Alkalinity, mg/L as $CaCO_3$	59	57	68	68	45	45	67	67		
Calcium, mg/L as $CaCO_3$	42	42	36	36	31	30	39	39		
Conductivity, μmhos/cm at 25°C	136	44	142	149	11	106	134	132		
Orthophosphate, mg/L as PO_4[1]										
Silicate, mg/L as SiO_2[1]										
(OTHER)[2]										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										
(OTHER)										

1 Only required if PO_4 or SiO_2 is applied in the treatment process.

2 See ___ for list of other parameters that may be useful in examination of corrosion control options.

To convert from:	**to:**	
Phosphate, mg/L as P	mg/L as PO_4	multiply by 3
Calcium, mg/L as Ca	mg/L as $Ca\ CO_3$	multiple by 2.5
Temperature in °F	°C	subtract 32, then divide by 1.8
Alkalinity in meq/L	mg/L as $CaCO_3$	multiply by 50

Appendix B
Treatment Alternatives and Secondary Impacts

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Appendix B
Treatment Alternatives and Secondary Impacts

The USEPA has identified three corrosion control treatment approaches for drinking water systems. The three approaches include (1) alkalinity and pH adjustment, (2) corrosion inhibitors, and (3) calcium adjustment. The first two treatment approaches (pH/alkalinity adjustment and corrosion inhibitor) occur by a mechanism known as passivation. The third treatment approach (calcium adjustment) occurs by a mechanism known as precipitation or barrier protection. These three corrosion control treatment approaches and their potential secondary impacts on a water system are discussed below.

B.1 Alkalinity and pH Adjustment

pH and/or alkalinity adjustment can be used to control lead and copper corrosion of pipe material in the distribution system. This form of corrosion control occurs by passivation, which is a mechanism whereby the potable water supply and pipe material interact chemically to form an insoluble film on the pipe surface. pH/alkalinity adjustment can be accomplished by adding caustic soda (NaOH), lime ($Ca(OH)_2$), soda ash (Na_2CO_3), carbon dioxide (CO_2), or sodium bicarbonate ($NaHCO_3$). A summary of chemicals used to adjust pH and alkalinity is included as Table B-1.

The addition of caustic soda or lime to a potable water supply typically causes a small increase in alkalinity. The addition of soda ash or sodium bicarbonate can cause a substantial increase in alkalinity while not altering significantly the water pH. According to metals solubility theory, high pH conditions (approximate pH of 10) and low alkalinity (30-50 mg/L as $CaCO_3$) tend to favor minimum lead and copper solubility. However, it typically is not practical for utilities to serve water with such high pH. The solubility of copper appears to be more strongly related to pH compared to the solubility of lead (USEPA, 1992).

As an alternative to chemical treatment, pH adjustment also can be achieved by aerating water to remove CO_2 from the source. Carbon dioxide levels typically are low in surface water sources, but CO_2 can be as high as 20 to 40 mg/L in ground water sources. According to Larsen (1994), aeration technology can become cost effective when flows are greater than approximately 0.5 MGD and CO_2 concentrations are greater than 15 mg/L. In addition to increasing pH, aeration technology also can cause the removal of radon and/or VOCs that may be present in the source.

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Table B-1
Summary of Chemicals Typically Used in pH/Alkalinity and Calcium Adjustment Corrosion Control Treatment

Chemical	Use	Composition	Theoretical Alkalinity Change	Notes
Caustic Soda, NaOH	Raise pH. Convert excess CO_2 to alkalinity species.	93% purity liquid bulk. Colder climates, bulk storage at <50% purity to prevent freezing.	1.25 mg/L* $CaCO_3$ alkalinity per mg/L as NaOH.	pH control is difficult when applied to poorly buffered water.
Lime, $Ca(OH)_2$	Raise pH. Increases alkalinity and calcium content.	95%- 98% purity as $Ca(OH)_2$. 74% active ingredient as CaO. Dry storage with slurry feed.	1.35 mg/L* $CaCO_3$ alkalinity per mg/L as $Ca(OH)_2$.	pH control is difficult when applied to poorly buffered waters. Slurry feed can cause turbidity. O&M intensive.
Soda Ash, Na_2CO_3	Increases alkalinity with moderate increase in pH.	95% purity. Dry storage with solution feed.	0.94 mg/L* $CaCO_3$ alkalinity per mg/L as Na_2CO_3.	More pH increase caused as compared to $NaHCO_3$, and less costly.
Carbon Dioxide, CO_2	Lowers pH. Converts excess hydroxyls to bicarbonate and carbonate species.	Pressurized gas storage. Fed either through eduction or directly.	None.	Can be used to enhance alkalinity with NaOH or lime feed systems.
Sodium Bicarbonate $NaHCO_3$	Increase alkalinity with little increase in pH.	98% purity. Dry storage with solution feed.	0.56 mg/L* $CaCO_3$ alkalinity per mg/L as $NaHCO_3$.	Good alkalinity adjustment choice, but very expensive.

Source: LCR Guidance Manual Volume II (1992).

* *These numbers are from an USEPA report* Corrosion Manual for Internal Corrosion of Water Distribution Systems, *1984.*

There are several disadvantages to increasing pH for corrosion control treatment. An increase in pH can reduce the effectiveness of chlorine as a disinfectant, increase the potential for manganese precipitation, and increase the formation of trihalomethanes in the distribution system.

B.2 Corrosion Inhibitors

Corrosion inhibitors are specially formulated chemicals characterized by their ability to form metal complexes and thereby reduce corrosion. Like pH/alkalinity adjustment, the corrosion control mechanism for inhibitors is passivation. Common corrosion inhibitors include phosphate-derivative compounds (e.g., orthophosphates, polyphosphates, and ortho-polyphosphate blends) and sodium silicates.

B.2.1 Orthophosphates

Orthophosphates have been shown to be very effective in controlling lead corrosion when used at the proper pH. The use of orthophosphates to inhibit lead and copper corrosion is most effective within the pH range of 7.4 to 7.8. At pH values greater than 7.8, metal phosphate precipitates can form, causing turbid water, scale build-up, and hydraulic capacity losses (USEPA, 1992). Waters with low hardness (calcium less than 16 mg/L as $CaCO_3$ and a calcium to magnesium ratio of 0.7) are well-suited for orthophosphate inhibitors, regardless of the alkalinity of the supply. Testing should be performed to evaluate the effectiveness of orthophosphates for specific systems.

The critical parameters to operating an orthophosphate corrosion control treatment program are: (1) maintaining a stable pH in the inhibitor's effective range throughout the distribution system; (2) determining the inhibitor composition best-suited for the specific water quality objectives and conditions; and (3) applying the appropriate dosage to accommodate background orthophosphate demand as well as the corrosion control protection sought.

A variety of orthophosphate compounds are available for corrosion control treatment including zinc orthophosphate, sodium orthophosphate, and poly-orthophosphate blends. Orthophosphate products typically are added to water at dosages ranging from 0.1 to 3 mg/L as P. In addition to corrosion control, the use of these products can increase levels of total dissolved solids, conductivity, and sodium (or zinc, depending on the product type) proportional to the applied orthophosphate dose.

Phosphate-based inhibitors are manufactured in a variety of compositions, including sodium orthophosphate, zinc orthophosphate, polyphosphates, and poly-orthophosphate blends. Each of these groups of compounds may have differing formulations as to the percentage of effective phosphate present. The selection of a specific inhibitor may require some preliminary testing. Extraordinary product claims have been made by the various vendors of inhibitor products, and oftentimes the formulation of a specific trade name product will remain proprietary. It is important to realize that there is little evidence to suggest that the proprietary formulations are in any way more effective than the generic blends for which the formulations are known.

Additionally, the proper application rate for a specific inhibitor should be determined through testing. As a preliminary assessment, the necessary dosage should include the phosphate-demand exerted by the water quality constituents present in the finished water. Beyond the dosage required for effective lead and/or copper control, metals present in the supply will combine with phosphates to differing degrees, imposing an effective "phosphate-demand." The final dosage required should be sufficient to accommodate the phosphate-demand and provide the effective inhibitor residual necessary to achieve lead and/or copper corrosion control.

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Under certain conditions, the use of phosphate inhibitors may provide enough phosphate to a water system to stimulate algae growth. This condition potentially can occur in open reservoirs where temperature, sunlight and nutrient supplies are favorable for growth.

B.2.2 Polyphosphates

Polyphosphates have been used for many years as sequestering agents for the control of iron and manganese precipitation, and as corrosion inhibitors for steel pipe. Polyphosphates generally are most effective at dosages ranging from 2 to 5 mg/L as P and low pH (from 5 to 7). The most common application form of polyphosphates is as a blend with orthophosphate. With time, polyphosphates can revert back to orthophosphates, resulting in an increase in orthophosphate ion. Thus, secondary effects of polyphosphates are similar to orthophosphates discussed previously.

When used in conjunction with a low pH, polyphosphates have a tendency to corrode asbestos cement (AC) pipe. A chemical reaction (known as chelation) can occur between polyphosphates and calcium to cause a deterioration in the pipe wall, which eventually leads to the release of asbestos fibers. This phenomena is opposite to the observed effects of zinc orthophosphate on AC pipe. When used in conjunction with a higher pH (7.5 to 8.5), the zinc orthophosphate can help "heal" deteriorated AC pipe.

B.2.3 Silicates

Silicate-based inhibitors are produced as various mixtures of silicate (SiO_2) and alkali (Na_2O or K_2O). The mechanism involved in controlling corrosion by silicate application is unclear, but it may include absorption and formation of less soluble metal-silicate compounds. In addition to corrosion control, silicate-based inhibitors can sequester iron and manganese present in source water and reduce red and black water events. Recent studies suggest that corrosion control by silicate-based inhibitors may not be as effective as previously believed for the control of copper corrosion (Reiber, 1994).

Silicates appear to control corrosion by a combination of absorption and formation of less soluble metal-silicate compounds. Silicates are considered anodic inhibitors, combining with the free metal released at the anode site of corrosion activity and forming an insoluble metal-silicate compound. These corrosion products crystallize to form a protective barrier on the face of pipe walls. However, microscopic and x-ray examinations have shown two layers of film on pipes conveying water treated with silicates. The majority of the silicate appears in the uppermost layer adjacent to the water. This film is an amorphous silicate film adhered to the underlying silicate-metal surface. A

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slightly corroded surface may be necessary to form the protective silicate film. However, the application of silicates in a distribution system with extensive corrosion by-product build-up may result in their release, causing red and turbid water problems (LCR Guidance Manual, Volume II).

Like the use of phosphate inhibitors, silicates can combine with other constituents in the delivered water besides the materials targeted for protection. Therefore, sufficient dosages must be applied to compensate for the consumption of silicate by other metals or cations. Specifically, calcium and magnesium will readily react with silica over a large pH range and silica can sequester soluble iron and manganese present in the source water to reduce red (iron) and black (manganese) water events. Attention to the water quality conditions prior to their application is necessary depending on the intended use and performance of the silicate. For poorly to moderately buffered waters, the relatively caustic silicate solutions offer the added advantage of pH control.

B.3 Calcium Adjustment

The formation of a calcium carbonate precipitate may be used to coat the interior walls of pipes and thereby reduce the corrosion of the pipe surface. This mechanism is known as precipitation, and the success of this method depends on the ability to form precipitates in the water (i.e., supersaturated conditions) and the resultant characteristics of the deposit on the pipe wall (e.g., permeability, adherence strength, and uniformity). Success also depends on the ability to control the formation of scale buildup to insure that hydraulic capacity is not unduly sacrificed to provide corrosion protection.

In general, the solubility of calcium carbonate in water decreases with increasing pH. (Open systems could involve dissolving and de-gassing of carbon dioxide, which also would affect calcium carbonate solubility.) Thus, more calcium carbonate will precipitate rather than stay in solution at higher pH values. The chemical feed system for this corrosion control treatment may include the same chemicals used for pH/alkalinity adjustment, but the goals would be different and higher dosages would be required to target pH, carbonate content (alkalinity), and calcium concentration necessary to achieve calcium carbonate precipitation.

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Appendix C
Responses to Auburn Survey

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

1. What type of processes do you use that require water? (i.e., cooling, electroplating):

Domestic water supply (not a process)
Heating & Cooling loops for facility climate control

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☒ Yes ☐ No

If yes, please explain: Small increase in water treatment chemicals for boilers.

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☒ Yes ☐ No

If yes, please explain: Small increase in water treatment chemicals for boilers.

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☒ No

If yes, please explain:

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations? ☐ Yes ☒ No

If yes, please explain:

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6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☐ Yes ☒ No

If yes, please explain: Possible increase on pump wear,

7. Are there observations or information you would like us to consider during the study?

Let us know if the changes are made.

Name of Business: Auburn School District
Address: 615 15th St SW
Phone: 931-4955
Contact: Bryan Welsh or Norm Alexander
Date: 10-26-94

Please return:
Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

City of Auburn
25 West Main
Auburn, WA 98001

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

1. What type of processes do you use that require water? (i.e., cooling, electroplating):

drinking, cooking, washing

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☐ Yes ☑ No

If yes, please explain: as long as it remains at a safe level for consumption

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☐ Yes ☑ No

If yes, please explain: see # 2

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☑ No

If yes, please explain: See #2

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations?

☐ Yes ☑ No

If yes, please explain: No - See #2

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6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☐ Yes ☑ No

If yes, please explain: See #2

7. Are there observations or information you would like us to consider during the study?

corrosion has impacted our facility in the past and appreciate any work to be done to prevent further problems

Name of Business:
Address: Childhaven
1345 22nd St. NE Auburn 98002
Phone: 833-5908 Date: 9/30/94
Contact: Marlene Carter

Please return: Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

City of Auburn
25 West Main
Auburn, WA 98001

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

1. What type of processes do you use that require water? (i.e., cooling, electroplating):

10% irrigation

90% Consumption

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☐ Yes ☐ No ?

If yes, please explain: ____________________

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☐ Yes ☐ No ?

If yes, please explain: ____________________

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☐ No ?

If yes, please explain: ____________________

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations? ☐ Yes ☐ No ?

If yes, please explain: ____________________

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6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☐ Yes ☐ No ?

If yes, please explain: __________

7. Are there observations or information you would like us to consider during the study?

____

Name of Business: The River Mobile Estates
Address: 3611 I ST. N.E.
AUBURN WA 98002
Phone: 833-4661 Date: 9/27/94
Contact: Louise & Forrest DeRochie - mgrs

Please return: Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

City of Auburn
25 West Main
Auburn, WA 98001

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I'm sorry but we do not know the answers to your questions -

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

1. What type of processes do you use that require water? (i.e., cooling, electroplating):

Space heating, household cleaning, cooking

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☐ Yes ☐ No

If yes, please explain: ?

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☐ Yes ☐ No

If yes, please explain: ?

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☐ No

If yes, please explain: ?

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations? ☐ Yes ☐ No

If yes, please explain: ?

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6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☐ Yes ☐ No

If yes, please explain: ?

7. Are there observations or information you would like us to consider during the study?

What are the effects of these possible changes on hot water heating lines?

Name of Business: King County Housing Authority
Address: 15455 65th Ave So
Seattle, WA 98188
Phone: 241-4237 Date: Sept 26, 1994
Contact: Tom Tasa

Please return: Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

City of Auburn
25 West Main
Auburn, WA 98001

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

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1. What type of processes do you use that require water? (i.e., cooling, electroplating):

SHOWERS, SINKS, KITCHEN, HEAT PUMPS (COOLING & HEATING), BOILERS, MEDICAL STERILIZERS

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☐ Yes ☒ No

If yes, please explain: NONE KNOWN

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☐ Yes ☒ No

If yes, please explain: DON'T KNOW

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☒ No

If yes, please explain: DON'T KNOW

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations? ☐ Yes ☒ No

If yes, please explain: DON'T KNOW

6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☒ Yes ☐ No

If yes, please explain: SILICA IS VERY HARD ON BOILERS & CANNOT BE REMOVED PRIOR TO INJECTION. ANY EXTRA SILICA IS NOT DESIRED

7. Are there observations or information you would like us to consider during the study?

Name of Business: AUBURN GENERAL HOSPITAL
Address: 20 SECOND ST NE

Phone: 833-7711 Date: 22 SEPT 94
Contact: RICH LOCKE

Please return: Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

City of Auburn
25 West Main
Auburn, WA 98001

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

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1. What type of processes do you use that require water? (i.e., cooling, electroplating):

Residential Customers, Landscape for Plants, Trees, Grass
Swimming Pool

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☐ Yes ☒ No

If yes, please explain: ______

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☐ Yes ☒ No

If yes, please explain: ______

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☐ No

If yes, please explain: ______

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations? ☐ Yes ☐ No

If yes, please explain: ______

6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☐ Yes ☐ No

If yes, please explain: ______

7. Are there observations or information you would like us to consider during the study?

______

Name of Business: RIo Verde moBiLe ESTATes
Address: 1402 22Nd ST #200
AUBURN Wa 98002
Phone: 833-7338 Date: 9-21-94
Contact: Joyce HoLem

Please return: Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

TACOMA, WA 984
1994
PM

City of Auburn
25 West Main
Auburn, WA 98001

Nass Diallo
City of Auburn
25 West main
Auburn Wa 98001

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Auburn Survey on Water Corrosion Treatment

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect your water use.

1. What type of processes do you use that require water? (i.e., cooling, electroplating):

Refrigeration cooling towers

2. If Auburn water pH was raised from 6.8 to 7.5, would there be an adverse impact on your operations?

☒ Yes ☐ No

If yes, please explain: We would have to Re-ADjust our cooling water treatment

3. If Auburn water pH was raised from 6.8 to 8.0, would there be an adverse impact on your operations?

☒ Yes ☐ No

If yes, please explain: Same as #2

4. Would an additional 0.5 mg/L of zinc in Auburn water have adverse impacts on your operations?

☐ Yes ☒ No

If yes, please explain:

5. Would an additional 0.5–2 mg/L of orthophosphate in Auburn water have adverse impacts on your operations? ☐ Yes ☒ No

If yes, please explain:

DRAFT

6. Would an additional 5–10 mg/L of silica in Auburn water have adverse impacts on your operations? ☒ Yes ☐ No

If yes, please explain: IT would cause a buildup of scale in the cooling towers

7. Are there observations or information you would like us to consider during the study?

NO

Name of Business: Supervalu west coast Grocery Division
Address: 701 15 SW.
Auburn wa 98002
Phone: 206-838-9080
Date: 9-23-94
Contact: Mel Glover

Please return: Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066. Thank you for taking the time to complete this survey.

City of Auburn
25 West Main
Auburn, WA 98001

Place Stamp Here

DRAFT

Auburn Corrosion Study
Plumbing Shop Questionnaire

The City of Auburn is researching new treatment options to reduce the corrosion into our water system. Even though our water meets overall quality standards, we must enhance our water treatment methods to reduce corrosion if it can be done without hurting the overall quality of our water. Please take a few minutes to answer the following questions so we can know how our treatment options will affect internal pipe corrosion.

Name of Plumbing Shop: Sound Mechanical & Industrial
Address: 703 24th SE
Auburn, Wa. 98002
Phone: 735-1857 Date: 9/26/94
Contact: Matt

Is corrosion on the inside of water facilities a major problem in the Auburn area?

Explain: ? N/A

Is corrosion on the inside of water facilities similar throughout the Auburn area?

Explain: N/A

Are different types of plumbing materials associated with the age of the building?

If yes, provide examples: ?

Are different types of plumbing materials associated with the different types of buildings?

If yes, provide examples: ?

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Describe typical failures of the following pipe materials.

Galvanized: Underground: Leak through corrosion
~~Above At~~ In structure: blockage

Copper: Pin holes due to corrosion or electrolosis

Other:

Is corrosion different in hot vs. cold water systems?

If yes, provide examples: Hot normally first
Type 'M' more than Type 'L'

What is the expected life of the following pipe materials?

Galvanized: 40-50 Copper: 50+ Other:

What is the average plumbing system replacement cost (per unit) for the following:

Single-Family Dwelling: 2,000^{00}
Multi-Family Dwelling: 2500^{00}-3,000^{00}

Please return:
Nass Diallo
City of Auburn
25 West Main
Auburn, WA 98001

If you have further questions, contact Nass Diallo at (206) 931-3010 or Bill Scheder at (206) 931-3066.

Thank you for taking the time to complete this survey.

DRAFT

Appendix D
Spreadsheet Calculations for System-Wide Blended pH

DRAFT

Table D-1
Auburn Water System
Existing and Future Conditions
Estimated Water pH for System-Wide Blends

Source Name	DOH ID	Annual Average Flow								
		1992-93			1994			2010		
		pH	(MGD)	(%)	pH	(MGD)	(%)	pH	(MGD)	(%)
Coal Creek Springs	S01	6.49	3.5	50.0	6.49	4.1	53.9	6.49	4.1	28.3
West Hill Springs	S02	6.50	0	0.0	6.50	0.7	9.2	6.50	0.7	4.8
Well 1	S03	6.39	1.7	24.3	6.39	1	13.2	6.39	1	6.9
Well 2	S04	6.44	0.7	10.0	6.44	1.7	22.4	6.44	3.4	23.4
Wells 3A and 3B (1)	S05 & S08	6.65	0	0.0	6.65	0	0.0	6.65	2	13.8
Well 4	S06	6.30	1	14.3	6.30	0	0.0	6.30	3.2	22.1
Wells 5 and 5A	S07 & S09	6.81	0.1	1.4	6.81	0.1	1.3	6.81	0.1	0.7
Total			**7.00**	**100.0**		**7.60**	**100.0**		**14.50**	**100.0**
Estimated pH of Blend (2)				6.43			6.46			6.44

(1) Assumes future production from Wells 3A and 3B or new sources to meet future demand for the system.
(2) Estimated pH of blend does not include water from Wells 5 and 5A, which serve the Lakeland Hills area only.

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Table D-2
Auburn Water System
Stage 1 Treatment
Estimated Water pH for System-Wide Blends

Source Name	DOH ID	Annual Average Flow					
		1994			2010		
		pH	(MGD)	(%)	pH	(MGD)	(%)
Coal Creek Springs	S01	7.50	4.1	53.9	7.50	4.1	28.3
West Hill Springs	S02	6.50	0.7	9.2	6.50	0.7	4.8
Well 1	S03	6.39	1	13.2	6.39	1	6.9
Well 2	S04	7.50	1.7	22.4	7.50	3.4	23.4
Wells 3A and 3B (1)	S05 & S08	6.65	0	0.0	6.65	2	13.8
Well 4	S06	6.30	0	0.0	6.30	3.2	22.1
Wells 5 and 5A	S07 & S09	6.81	0.1	1.3	6.81	0.1	0.7
Total			**7.60**	**100.0**		**14.50**	**100.0**
Estimated pH of Blend (2)				6.97			6.69

(1) Assumes future production from Wells 3A and 3B or new sources to meet future demand for the system.
(2) Estimated pH of blend does not include water from Wells 5 and 5A, which serve the Lakeland Hills area only.

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Table D-3
Auburn Water System
Stage 2 Treatment
Estimated Water pH for System-Wide Blends

		Annual Average Flow					
		1994			2010		
Source Name	DOH ID	pH	(MGD)	(%)	pH	(MGD)	(%)
Coal Creek Springs	S01	7.50	4.1	53.9	7.50	4.1	28.3
West Hill Springs	S02	6.50	0.7	9.2	6.50	0.7	4.8
Well 1	S03	7.50	1	13.2	7.50	1	6.9
Well 2	S04	7.50	1.7	22.4	7.50	3.4	23.4
Wells 3A and 3B (1)	S05 & S08	6.65	0	0.0	6.65	2	13.8
Well 4	S06	6.30	0	0.0	6.30	3.2	22.1
Wells 5 and 5A	S07 & S09	6.81	0.1	1.3	6.81	0.1	0.7
Total			**7.60**	**100.0**		**14.50**	**100.0**
Estimated pH of Blend (2)				7.24			6.75

(1) Assumes future production from Wells 3A and 3B or new sources to meet future demand for the system.
(2) Estimated pH of blend does not include water from Wells 5 and 5A, which serve the Lakeland Hills area only.

Table D-4
Auburn Water System
Stage 3 Treatment
Estimated Water pH for System-Wide Blends

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Source Name	DOH ID	Annual Average Flow					
		1994			2010		
		pH	(MGD)	(%)	pH	(MGD)	(%)
Coal Creek Springs	S01	7.50	4.1	53.9	7.50	4.1	28.3
West Hill Springs	S02	6.50	0.7	9.2	6.50	0.7	4.8
Well 1	S03	7.50	1	13.2	7.50	1	6.9
Well 2	S04	7.50	1.7	22.4	7.50	3.4	23.4
Wells 3A and 3B (1)	S05 & S08	6.65	0	0.0	6.65	2	13.8
Well 4	S06	7.50	0	0.0	7.50	3.2	22.1
Wells 5 and 5A	S07 & S09	6.81	0.1	1.3	6.81	0.1	0.7
Total			**7.60**	**100.0**		**14.50**	**100.0**
Estimated pH of Blend (2)				7.24			7.14

(1) Assumes future production from Wells 3A and 3B or new sources to meet future demand for the system.

(2) Estimated pH of blend does not include water from Wells 5 and 5A, which serve the Lakeland Hills area only.

Table D-5
Auburn Water System
Stage 4 Treatment
Estimated Water pH for System-Wide Blends

		Annual Average Flow					
		1994			2010		
Source Name	**DOH ID**	**pH**	**(MGD)**	**(%)**	**pH**	**(MGD)**	**(%)**
Coal Creek Springs	S01	7.50	4.1	53.9	7.50	4.1	28.3
West Hill Springs	S02	7.50	0.7	9.2	7.50	0.7	4.8
Well 1	S03	7.50	1	13.2	7.50	1	6.9
Well 2	S04	7.50	1.7	22.4	7.50	3.4	23.4
Wells 3A and 3B (1)	S05 & S08	6.65	0	0.0	6.65	2	13.8
Well 4	S06	7.50	0	0.0	7.50	3.2	22.1
Wells 5 and 5A	S07 & S09	6.81	0.1	1.3	6.81	0.1	0.7
Total			**7.60**	**100.0**		**14.50**	**100.0**
Estimated pH of Blend (2)				7.50			7.23

(1) Assumes future production from Wells 3A and 3B or new sources to meet future demand for the system.
(2) Estimated pH of blend does not include water from Wells 5 and 5A, which serve the Lakeland Hills area only.

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Appendix E
Conceptual Diagrams for Caustic Feed and Aeration Treatment Facilities

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Appendix E
Conceptual Diagrams for Caustic Feed and Aeration Treatment Facilities

Facility Concepts

Facility concept sketches have been developed to show the general size and configuration of corrosion control facilities typical of those which may be developed to serve the needs of City of Auburn Water System.

The sketches are based upon information available at the time of the corrosion control study and report. Work which will be performed during predesign and final design phases may result in significant modification in the appearance, configuration and size of the required corrosion control facilities.

Caustic Feed

The facility depicted in Exhibit E-1 is capable of receiving, storing and feeding caustic soda (NaOH) to a water system for the purpose of elevating the pH of the water. The facility shown in sized for the approximate requirements of a pH adjustment facility located at the City's 4.3 mgd Coal Creek springs water source. Most of the system elements shown would be present in a caustic feed facility designed for other locations in the system. Major system elements include the following:

☐ Caustic storage tank (or tanks) capable of holding from 15 to 20 days supply of treatment chemical.

☐ Redundant metering pumps (2) capable of feeding up to 35 milligrams per liter of 50% NaOH solution.

☐ Spill containment walls, sump and alarm.

☐ Internal piping and water supply pipeline solution injector.

☐ Flow measurement and pH analysis/alarm systems.

☐ Motor control and instrumentation center.

☐ Building enclosure with approximate footprint of 17 feet by 30 feet with maximum height of 15 feet.

No facilities for chlorine addition are shown since these functions are provided at other nearby facilities.

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Facility Concept—Aeration

The facility depicted in Exhibit E-2 is capable of aerating a water supply and reducing the carbon dioxide concentration through air stripping for the purpose of elevating the pH of the water. The facility would also reduce the concentrations of other volatile substances in the aerated water. The facility shown is sized for the approximate requirements of a pH adjustment facility located at the City's 4.3 mgd Well 2 water source. Most of the system elements shown would be present in an aeration facility designed for other locations in the system. Major system elements include:

- ☐ Packed tower aeration unit approximately 10 feet in diameter and 24 feet in height. The tower would contain media (small plastic geometric shapes to promote air-water contact), influent piping and distributor, media supports, air plenum and aerated water chamber.
- ☐ Air supply fan.
- ☐ Clearwell and redundant service pumps (2) required to boost the tower effluent to system pressures.
- ☐ Internal piping including distribution, overflow, tower effluent and service pump piping.
- ☐ Facilities for storing and feeding chlorine gas for disinfection purposes.
- ☐ Motor control and instrumentation center.
- ☐ Building enclosure with approximate footprint of 23 feet by 39 feet with maximum height of 15 feet. The total height of the facility would be approximately 24 feet (tower height).

The tower distribution piping is supplied directly from the existing pump at Well 2. A new back pressure sustaining control valve will be required at Well 2. A by-pass line (not shown) will be required to allow the system to be fed directly from Well 2 (as presently configured) during periods when the aeration facility is off line for maintenance.

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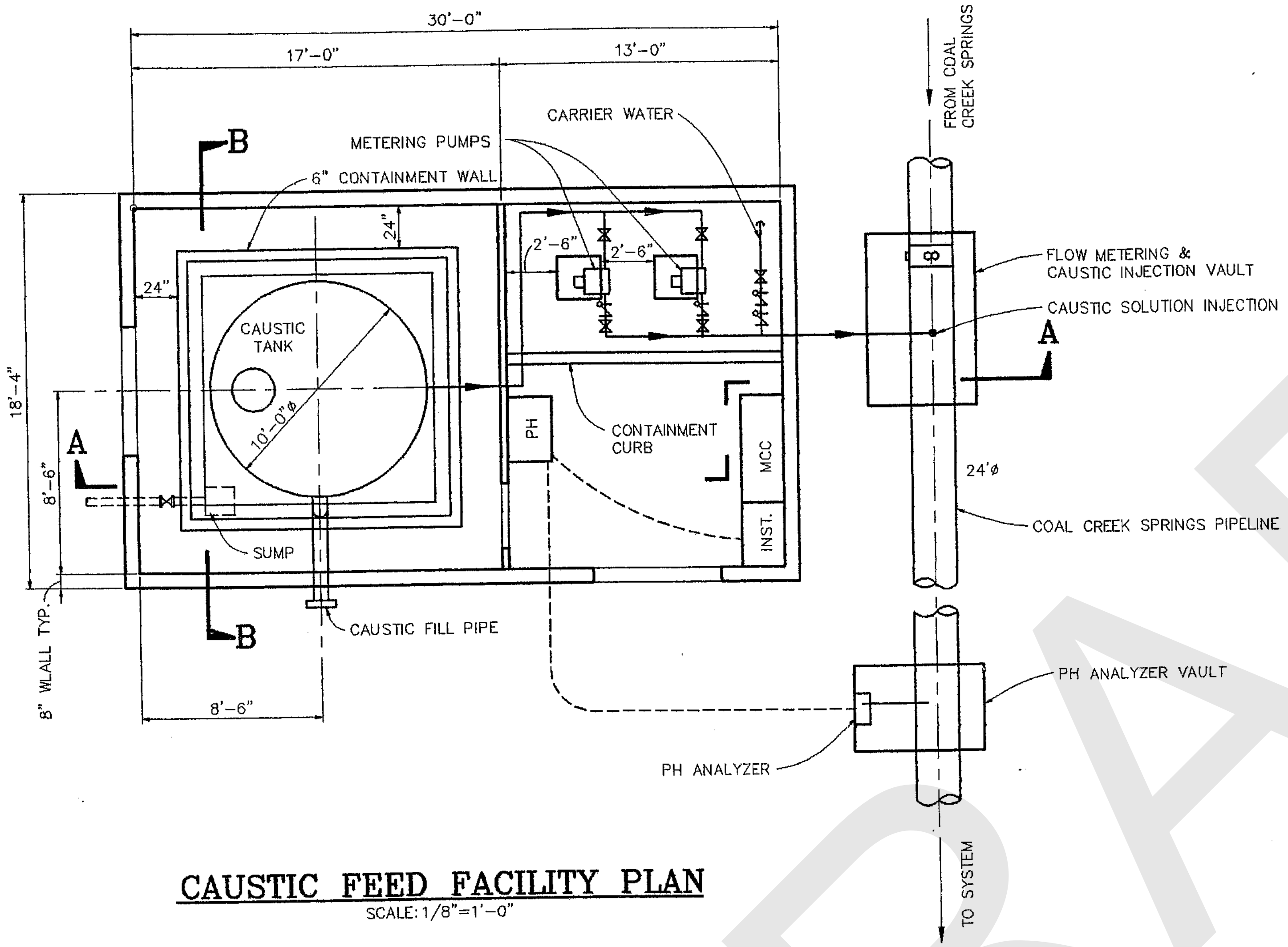
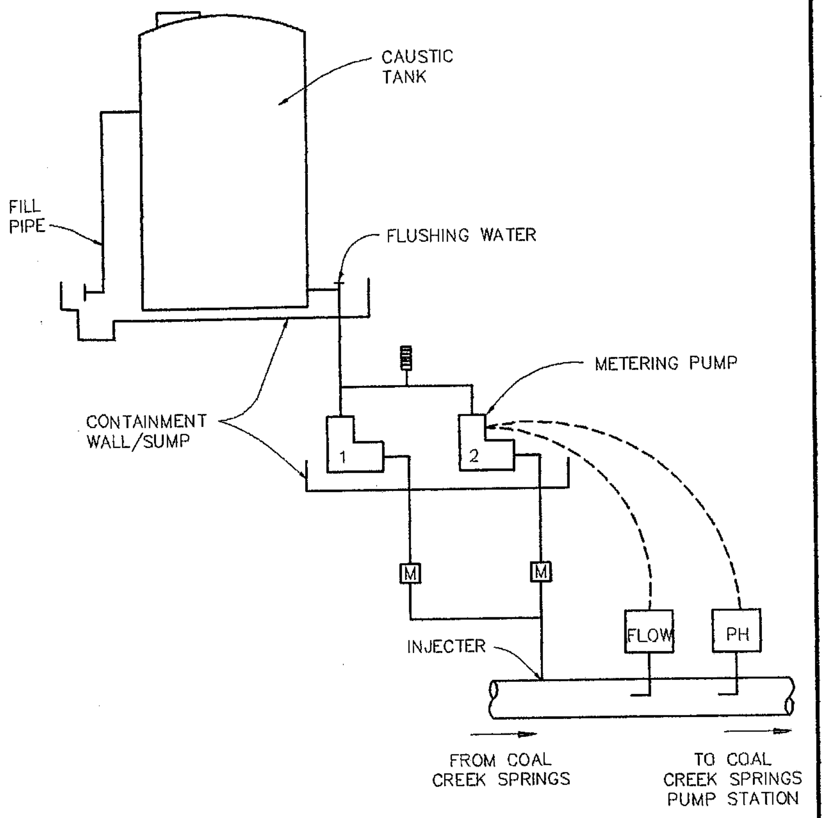


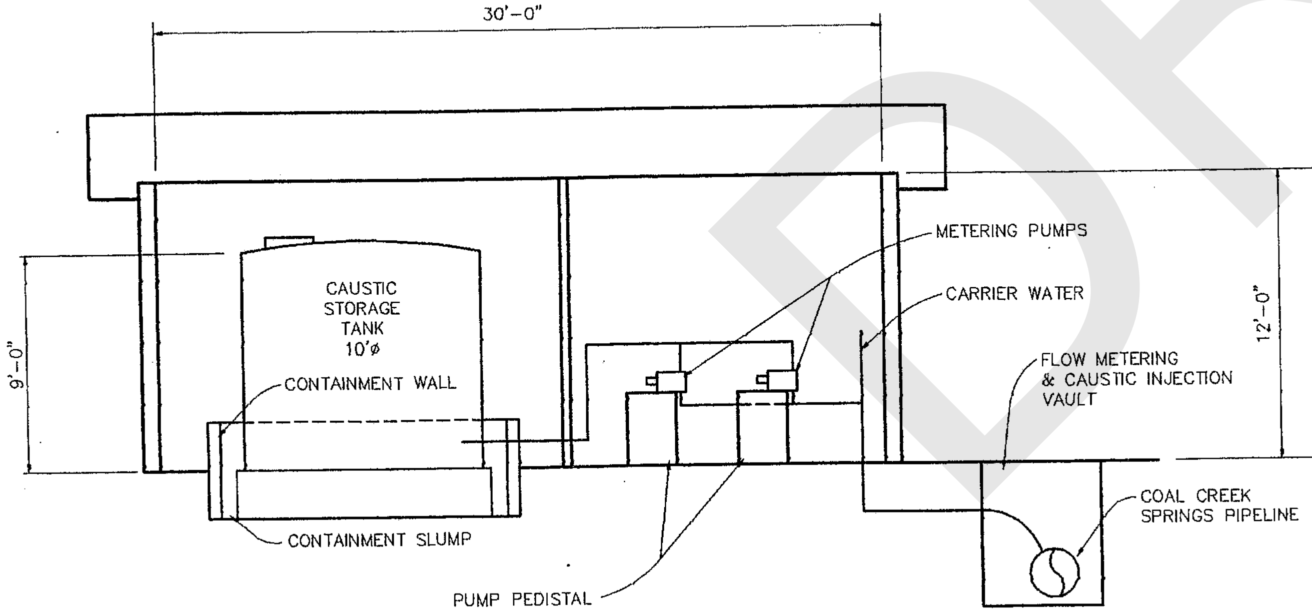
CAUSTIC FEED FACILITY PLAN

SCALE: 1/8"=1'-0"



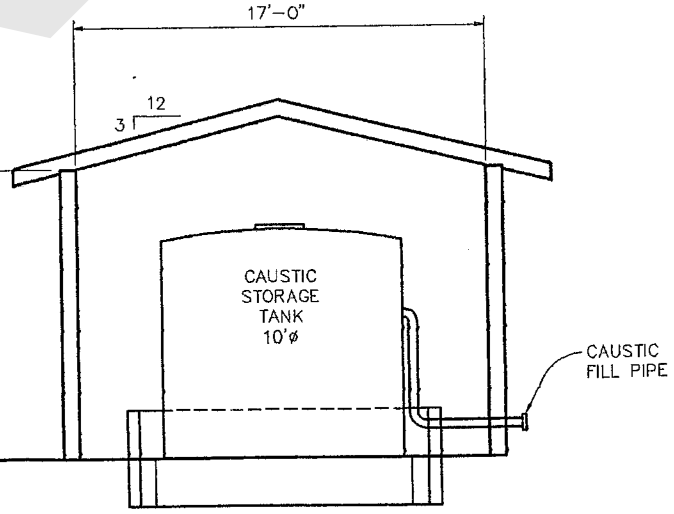
CAUSTIC FEED FACILITY SCHEMATIC

NTS



SECTION A–A

SCALE: 1/8"=1'-0"



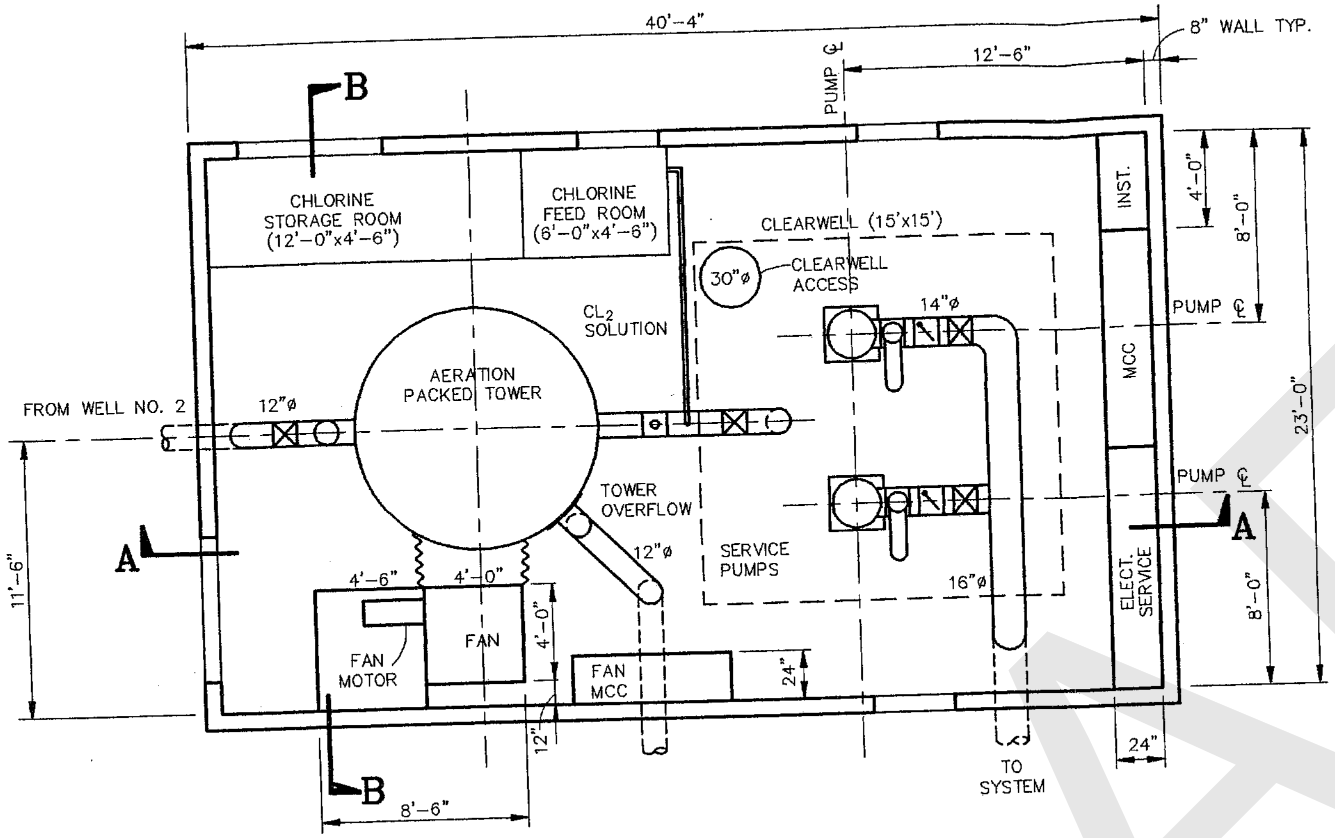
SECTION B–B

SCALE: 1/8"=1'-0"

EXHIBIT E-1
CITY OF AUBURN
COAL CREEK SPRINGS
CAUSTIC FEED FACILITY

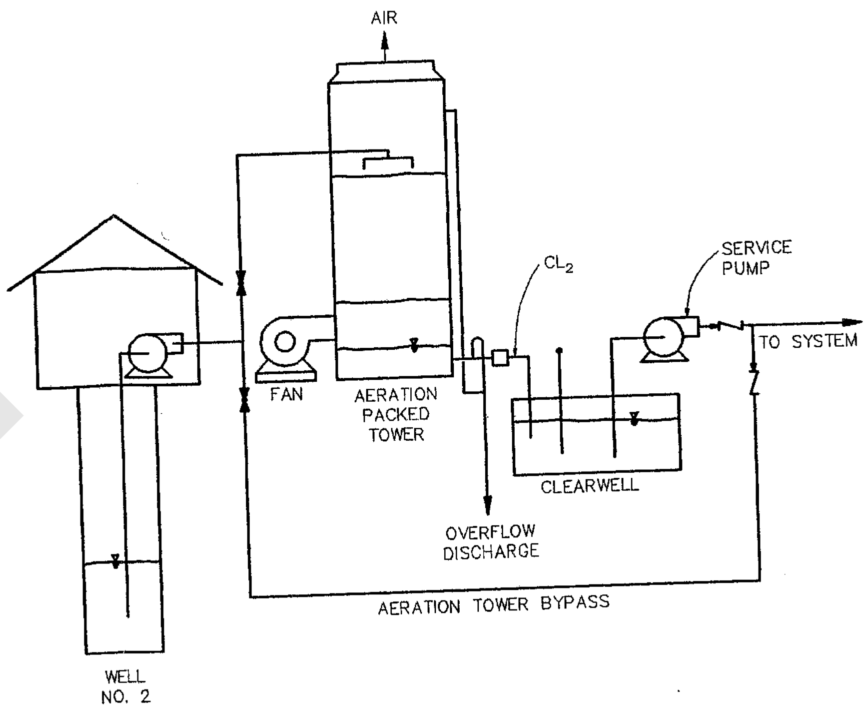
JUNE 1995

ECONOMIC AND ENGINEERING SERVICES, INC.



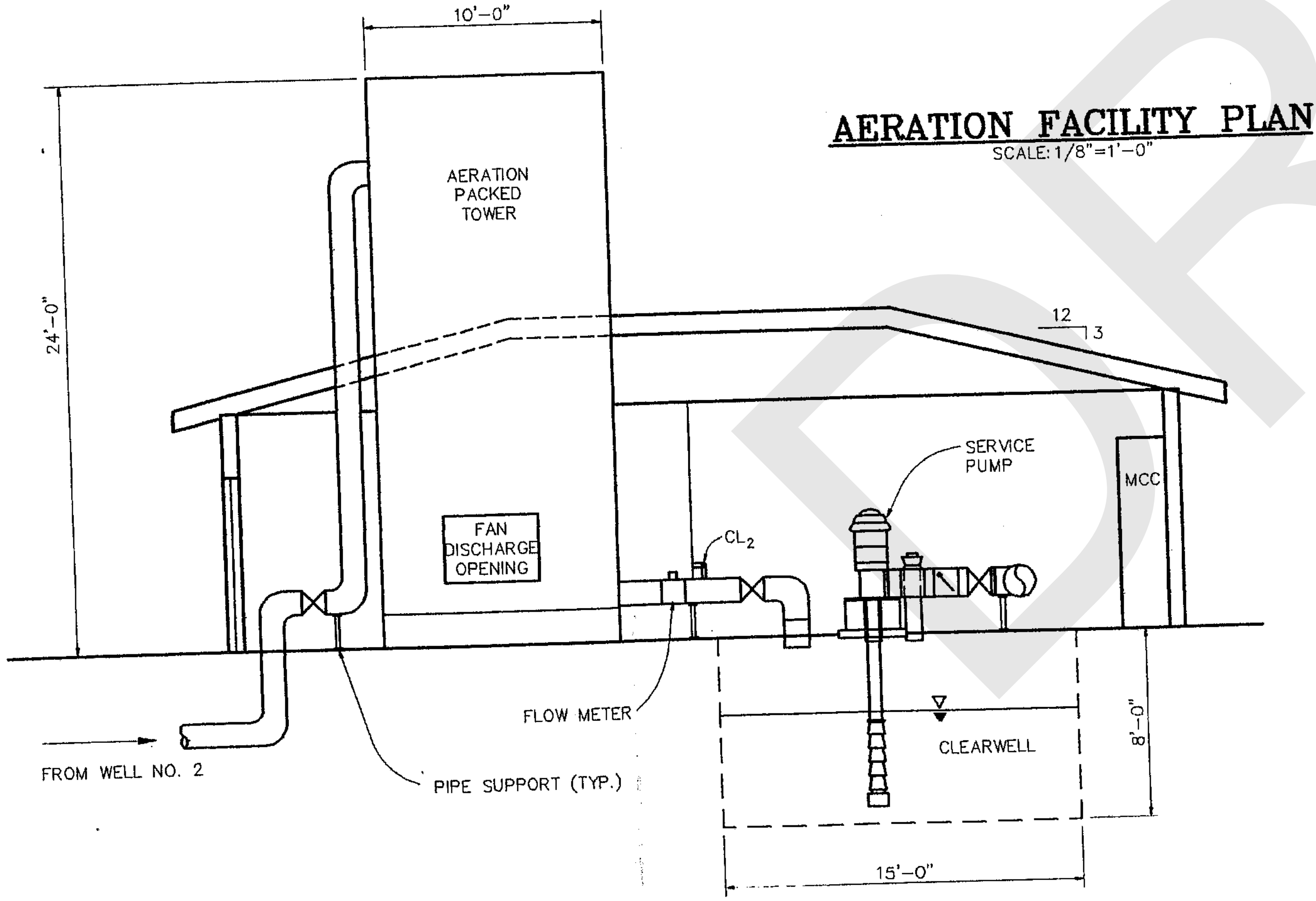
AERATION FACILITY PLAN

SCALE: 1/8"=1'-0"



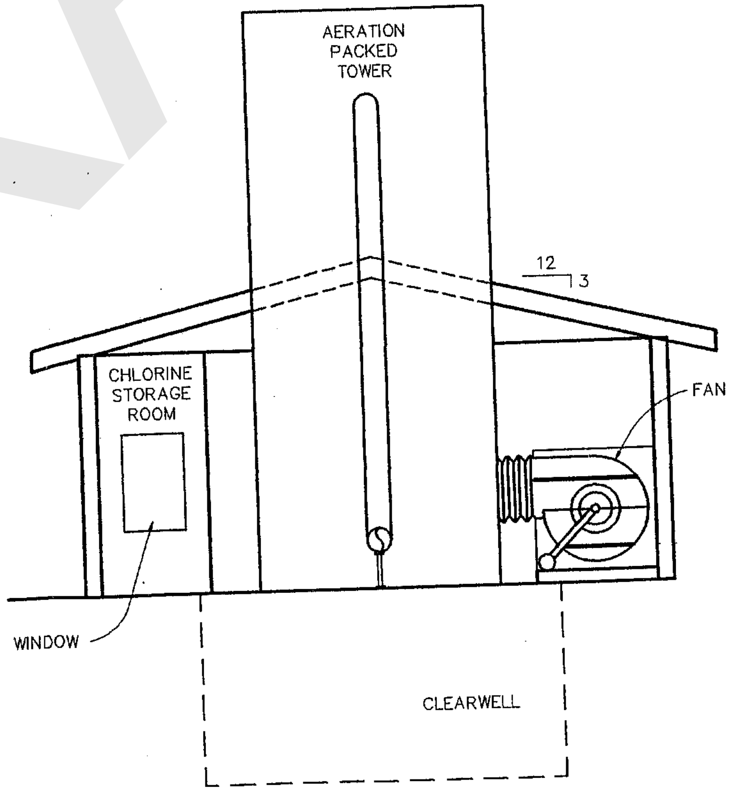
AERATION FACILITY SCHEMATIC

NTS



SECTION A-A

SCALE: 1/8"=1'-0"



SECTION B-B

SCALE: 1/8"=1'-0"

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EXHIBIT E-2
CITY OF AUBURN
WELL NO. 2
AERATION FACILITY

JUNE 1995

ECONOMIC AND ENGINEERING SERVICES, INC.

Appendix F
DOH Corrosion Control Report Form and Project Approval Application

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Washington State Department of Health
Division of Drinking Water

Lead & Copper
CORROSION CONTROL REPORT FORM

WATER SYSTEM INFORMATION

Water System Name:	City of Auburn
Water System ID#:	03350V
County:	King
System Contact Person:	Dwight Holobaugh
Phone Number:	(206) 931-3010
Address:	25 West Main Street Auburn, WA 98001

REPORT PREPARATION INFORMATION

Engineer overseeing preparation:	Gregory Kirmeyer
Contact person for report:	Glen Boyd
Phone Number:	(206) 451-8015
Company Name:	Economic and Engineering Services, Inc.
Address:	12011 Bel-Red Road, Suite 201 Bellevue, Washington 98005

** Important **

Also fill out and submit the Project Approval Application (see attachments). Under type of project, check the box for "other projects" and describe as corrosion control report.

The submittal must bear the seal and signature of a professional engineer licensed in the State of Washington and having specific expertise regarding design, operation, and maintenance of public water systems including corrosion control.

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OUTLINE

STEP 1. DEFINE EXISTING CONDITIONS

- 1(a). Corrosion Data Summary
    - Lead and Copper Rule monitoring results
    - any additional corrosion-related data
- 1(b). Interpreting the Data (source, treatment, distribution)
- 1(c). Summary of Historical Experience
    - complaints
    - plumbers survey
    - industrial customers interview
    - repair/replacement records
- 1(d). Water Quality Data for Other Regulations

STEP 2. EVALUATE NEED FOR SOURCE LEAD OR COPPER REMOVAL TREATMENT

STEP 3. EXAMINE CORROSION CONTROL EXPERIENCES

- 3(a). Previous Studies for this System
- 3(b). Analogous Systems
- 3(c). Literature Review

STEP 4. DEFINE CONSTRAINTS

- 4(a). Regulatory Constraints
- 4(b). Functional Constraints and Secondary Issues
    - planning
    - consecutive systems
    - blending issues
    - community impacts
    - compatibility with existing treatment
    - operational issues
    - system specific water quality goals

STEP 5. ELIMINATE UNSUITABLE APPROACHES

- pH/alkalinity adjustment
- calcium hardness adjustment
- phosphate inhibitor
- silicate inhibitor
- less corrosive source water

STEP 6. EVALUATE VIABLE APPROACHES

- 6(a). Develop Specific Alternatives for the Viable Approaches
- 6(b). Evaluate the Specific Scenarios
    - performance
    - feasibility
    - reliability
    - cost

STEP 7. RECOMMENDATION

- 7(a). Source Lead and Copper Removal Treatment
- 7(b). Full Scale Installation of Corrosion Control
- 7(c). Corrosion Control Demonstration Testing

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Refer to:

Section 2

STEP 1. DEFINE EXISTING CONDITIONS

The first step is to describe the existing conditions of the water system in terms of water quality and any evidence of corrosion activity. Because of the interrelation between corrosion control and compliance with other water quality regulations, this section will cover both corrosion related data and data related to other water quality issues.

Section 1 — 1(a). CORROSION DATA SUMMARY

Appendix A — 1(a-1). Use the MONITORING PERIOD DATA SUMMARY (attached) to summarize the LCR monitoring results for each monitoring period.

Sect. 2, 5 — 1(a-2). Was additional data examined for pH, alkalinity, conductivity, temperature, phosphate, and/or silicate? (e.g. monitoring to supplement minimum LCR requirements, treatment plant records, historical monitoring, special purpose monitoring)
If yes, describe the additional data. yes ✓ no _____

Sect. 5, 6, 7 — 1(a-3). Has the system examined data for other parameters or indices that may influence lead and copper corrosion? (see attached list of "Additional Water Quality Parameters that Play a Role in Corrosion.") If yes, provide discussion. yes ✓ no _____

— 1(b). INTERPRETING THE DATA (Source, Treatment, and Distribution)

Section 2 — 1(b-1). Source

Sect. 2.1.1 — 1(b-1.1). For each source, summarize
- DOH Source ID# and water system's name for the well
- the point-of-entry (POE) that the source feeds to
- frequency and duration of use
  (permanent, seasonal, or emergency source; months when source is typically used)
- pumping rate
- any known water quality problems particular to the source
- whether source is treated or untreated (including disinfection)

Sec. 2.1.1 — 1(b-1.2). Are there any current plans to develop new sources? If yes, describe. yes ✓ no _____

Sect. 2.2 — 1(b-1.3). Do any sources or POE's appear more corrosive than others?
e.g. based on - spatial distribution of lead and copper tap sample results
- WQP results
Some systems find it useful to plot results on a map to look for trends.
Provide discussion.

yes ✓
no significant difference _____
not possible to determine _____
does not apply (only 1 source) _____

— 1(b-1.4). Does source water quality have seasonal (climate influenced) variation? Discuss.
yes _____ no _____ not enough data to tell ✓

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Refer to:

— 1(b-2). Treatment

Sect. 2.3, Table 2-1 1(b-2.1). For each treatment facility, describe
- type of treatment
- purpose of treatment
- location of treatment
- time periods over which treatment is applied (e.g. continuous, seasonal, as needed)
- chemicals used
- chemical dosage (goal and typical ranges, how often adjusted)
- ranges of residual concentrations in distribution

Sect. 5, 7 1(b-2.2). Describe the influence of treatment on the WQPs. DOH may require analysis of raw water source samples as part of the review.

— 1(b-3). Distribution effects

Section 2.2.2 1(b-3.1). Are there WQP differences between points-of-entry and distribution? yes ____ no ✓

Sec. 2.1.5 1(b-3.2). Does the system conduct a flushing program? If yes, describe briefly. yes ✓ no ____

Sec. 2.1.4 and 2.1.5 1(b-3.3). Does the distribution system contain?

	Lead Service Lines (LSL)	Asbestos Cement (AC) Pipe	Unlined Cast Iron
yes		✓	✓
no	✓		
don't know			

If yes to LSL, attach map indicating areas of known or suspected lead service lines.
If yes to AC pipe, consider collecting the asbestos sample that is required by 1995.
(Call 206-361-2944 to obtain information on certified laboratories.)
If yes to unlined cast iron, is corrosion of this pipe a concern to the PWS?

— 1(c). SUMMARY OF HISTORICAL EXPERIENCE

Sec. 2.2.3 1(c-1). Complaints Provide "measurement" of complaints as shown below. If the PWS keeps records of complaints, these should be examined. If no records are available, the water system operators and managers should be able to rate these issues from experience. Provide discussion and description of typical complaints for categories rated 1, 2, or 3.

0 No complaints in this category
1 Occasional/infrequent complaints in this category
2 Several complaints in this category
3 Severe complaints in this category

Staining	1	Metallic Taste	0	
Color	1	Other Taste	1	
Sediment	1	Health-related	0	(nausea/cramps after drinking, dry skin/itching)
Odor	1	Other(specify)	0	

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Refer to:

Sec. 5.2.3 1(c-2). Have any of the following resources been used to assess the extent of corrosion activity?
- interview industrial customers yes __✓__ no ______
- review records of main & service line repair and replacement yes __✓__ no ______

If yes, provide brief summary.

— 1(d). WATER QUALITY DATA FOR OTHER REGULATIONS At minimum, discuss the following:

Sect. 5.1.1 1(d-1). Coliform and any other microbial sampling over the past two years

Sect. 5.1.1 1(d-2). Inorganic chemicals (IOC)
- any IOCs exceeding primary or secondary MCLs in the history of sampling
- potential for exceeding the asbestos MCL

Sec. 5.1.1 1(d-3). Any detection of VOC's or SOC's

Sec. 5.1.2 (d-4). Disinfection by-products (if available)
e.g.
- TTHM data
- natural organic matter data (TOC, DOC, UVabs)
- DBP formation potentials

Sec. 5.1.2 1(d-5). Radionuclides, including radon (if available)

Sec. 2.3 **STEP 2. EVALUATE NEED FOR SOURCE LEAD OR COPPER REMOVAL TREATMENT**

Do source water concentrations of lead and/or copper warrant investigation of treatment to remove these compounds from the source? If yes, provide evaluation of the alternatives. yes ______ no __✓__

Options for lead or copper removal from the source water include ion exchange, reverse osmosis, lime softening, and coagulation/filtration. When evaluating the need for source water treatment, you may refer to the *LCR Guidance Manual Volume 2: Corrosion Control Treatment* Section 3.3.4 on evaluating source water contributions.

— **STEP 3. EXAMINE CORROSION CONTROL EXPERIENCES**

– 3(a). PREVIOUS STUDIES

– 3(a-1). Have any corrosion control studies been conducted for this system? yes _____ no __✓__

If yes, provide discussion including
- date of study and who conducted study
- goals and options examined
- results, conclusions, and recommendations
- system's actions since completion of the study

– 3(a-2). Was corrosion control treatment implemented for this system? yes _____ no __✓__

If yes, discuss if or how the corrosivity of the treated water has changed as a result of treatment. (e.g. general observation, at-the-tap monitoring, coupons, frequency of complaints)

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Refer to:

Sect. 4 3(b). ANALOGOUS SYSTEMS

Has one or more analogous water system implementing a corrosion control program been identified in the area or through literature? yes __✓__ no ____

If yes, please provide the following information for each analogous system:

- PWS name and PWS ID# (if available)
- Justification of the analogous nature of the system (e.g. water quality data, lead and copper monitoring results, treatment, plumbing materials, system size)
- Description of any corrosion studies for the system (as in 3(a-1))
- If corrosion control has been installed, summarize lead and copper sampling results and any other measurements or observations of corrosion since installation

References 3(c). LITERATURE REVIEW

List references examined when preparing this report and discuss literature information pertinent to the decision-making process for this system that is not covered elsewhere in this report.

—

STEP 4. DEFINE CONSTRAINTS

Any constraint which could impact the feasibility of implementing an alternative treatment should be identified. Constraints are generally divided into two types: (1) regulatory constraints and (2) functional constraints/secondary impacts.

Sect. 5.1 4(a). REGULATORY CONSTRAINTS

By definition, the corrosion control treatment must not cause the system to violate any National Primary Drinking Water Regulation (NPDWR). Therefore, treatment approaches must be evaluated in terms of all NPDWRs.

Pages 3-27 to 3-33 and 3-57 in the *LCR Guidance Manual Volume 2: Corrosion Control Treatment* provide information to assist in this evaluation. Keep in mind that the Guidance Manual was published in 1992 and that there have been significant regulatory developments since that time.

Also, refer to the Washington State Board of Health Drinking Water Regulations Chapter 246-290 WAC.

For each applicable regulation, discuss the PWS's experience. For regulations of concern, determine the constraints for corrosion control to maintain compliance with the regulations.

Current primary drinking water regulations include:

Surface Water Treatment Rule
Coliform Rule
VOCs
IOC/SOC regulations
Radionuclides

Anticipated regulations that systems may wish to consider include:

Disinfection/Disinfection By-Products Rule
Radon Rule
Groundwater Disinfection Rule
Arsenic

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Refer to:

Sect. 5.2 4(b). **FUNCTIONAL CONSTRAINTS AND SECONDARY ISSUES**
Functional constraints must address, but are not limited to:

Sect. 5.2.1 4(b-1). Planning Considerations: Discuss items in the Water System Plan that will influence water quality or will have other implications for corrosion control.

Sect. 5.2.4 4(b-2). Consecutive Systems: Does the system sell water to other systems? yes __✓__ no _____
If yes,
- list the purchasing systems by name and ID#
- identify whether raw or finished water is purchased
- how are those systems being taken into account in the corrosion control decision process?

Sect. 5.2.2 and 5.2.4 4(b-3). Blending issues (multiple sources of varying water quality)
If applicable, discuss
- blending among sources owned by the system
- purchased water blended with sources owned by the system
- selling water to other systems

Sect. 5.2.3 4(b-4). Impacts on community
- Aesthetic impacts
  - Iron and manganese
  - Disturbing existing pipe coatings
  - Red water (microbial induced corrosion)
  - Taste and odor
  - Precipitation on household fixtures (silicates, hardness)
- Commercial/Industrial water quality needs
- Health-Care Facilities
- Wastewater permit limits (zinc, copper, and phosphate)

Sect. 5.2.5 4(b-5). Interference with any existing treatment processes

Sect. 5.2.6 4(b-6). Operational
- Appropriate technology for system size (complexity of operation and maintenance)
- Need for additional staff
- Staff training/certification
- Chemical hazards
- Reliability

Sect. 5.2.7 4(b-7). Any system specific water quality goals
- control of secondary contaminants (iron and manganese)
- corrosion control for other purposes
  - red water problems
  - increase plumbing service life
  - improve distribution hydraulics
- water quality consistency for interties
- other

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Refer to:

Section 6

STEP 5. ELIMINATE UNSUITABLE APPROACHES

Based on information in previous steps and referring to Figure 3-7 on page 3-23 of *LCR Guidance Manual Volume 2: Corrosion Control Treatment* (attached), can any approaches clearly be eliminated at this point?
Briefly describe the rationale for any approach determined to be unsuitable.

	Feasible approach?	
	Yes	No
pH/alkalinity adjustment (carbonate passivation for lead) (pH adjustment for copper)	✓	
calcium hardness adjustment (calcium carbonate precipitation)		✓
phosphate inhibitor (including pH adjustment if needed)	✓	
silicate inhibitor (including pH adjustment if needed)		✓
less corrosive source (e.g., new well, intertie, blending, etc.)	✓	

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Section 7

STEP 6. EVALUATE VIABLE APPROACHES

In this step specific scenarios are developed for the remaining viable approaches, and then compared to develop the recommendation. Many systems have found it useful to develop decision matrices tailored to constraints and issues specific to their system. By assigning numeric weights to the issues, a matrix provides a quantitative approach for decision making. A qualitative approach based on narrative justification is also acceptable.

Section 7 6(a). DEVELOP SPECIFIC ALTERNATIVES FOR THE VIABLE APPROACHES

For the remaining viable approaches in Step 5, develop specific alternatives for comparison.

Some possible factors to consider when developing the specific scenarios include
- the various WQP targets possible under each approach
- the chemical types and feed options available for each parameter adjustment
- possible modifications to existing treatment
- various options for switching or blending sources
- centralized treatment verses multiple treatment facilities for more than one source
- process control

6(b). EVALUATE THE SPECIFIC ALTERNATIVES in terms of:

Sec. 7.1 6(b-1). Performance: Anticipated relative effectiveness for reducing lead and copper concentrations based on analogous system experience, literature, and/or demonstration.

Sec. 7.2 6(b-2). Feasibility: In terms of regulatory and functional constraints identified in Step 4 and the PWS's treatment priorities.

Refer to:

Sec. 7.3 6(b-3). Reliability: In terms of operational consistency and continuous corrosion control protection.
- ability to maintain parameters within a reasonable range
- durability of the protective layer in case of mechanical failure or human error
- need for redundant components in the treatment system
- process control
- chemical supply integrity and availability

Sec. 7.4, Sect. 8.4 6(b-4). Cost: Identify the major components of each scenario and estimate the cost.

Sect. 7.6

STEP 7. RECOMMENDATION

Indicate the next step the system intends to pursue. Keep in mind that adjustments may be required if the system fails to meet the action levels after full scale installation of treatment. Demonstration (pilot) testing may be beneficial for evaluating the performance of one or more feasible options prior to making an investment in full-scale design and construction.

	Next Step?		
Source Treatment	Yes	No	
Remove lead and/or copper from the source water.		✓	If yes, see 7(a).
Corrosion Control			
Propose full-scale installation.	✓		If yes, see 7(b).
Conduct demonstration testing.		✓	If yes, see 7(c).

— 7(a). SOURCE LEAD AND COPPER REMOVAL TREATMENT

If the recommendation is to provide treatment for lead and copper removal from the source water, specify
- method of treatment (ion exchange, reverse osmosis, lime softening, coagulation/filtration)
- operating parameters to ensure adequate treatment

Section 8 7(b). FULL SCALE INSTALLATION OF CORROSION CONTROL

If the recommendation is full-scale implementation of one of the scenarios outlined in Step 6, provide a brief discussion of why this approach was chosen and summarize planned system improvements as outlined below:

— 7(b-1). If the program involves more reliance on or development of less corrosive sources, describe system improvements needed to implement the plan

— 7(b-2). For treatment, provide schematics of existing and proposed treatment processes for all sources to be treated indicating the feed location for each chemical

— 7(b-3). Fill in the pertinent parts of the table below to summarize:
- **Type of treatment**
- WQP goals (**targets**) at POEs that are expected to result in desired distribution water quality
- An estimate of the **operating ranges** that might reasonably be achieved at the POEs when aiming for the target concentrations
- **Design ranges** for sizing of treatment facilities to allow flexibility
- Types of **chemicals** that will be used to achieve the WQP goals

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Refer to:

Type of treatment: **pH adjustment**
(pH/alkalinity adjustment, $CaCO_3$ precipitation, PO_4, SiO_2)

Parameter	Target	Operating Range		Design Range		Chemical
		Min	Max	Min	Max	
pH	7.0					NaOH
Alkalinity, mg/L as $CaCO_3$						
Calcium, mg/L as Ca						
Phosphate, mg/L as PO_4						
Silicate, mg/L as SiO_2						
Chlorine, mg/L as Cl_2						

The PWS must install the treatment within 24 months after DOH either approves the recommended treatment or designates an alternative. Project report and construction documents must be submitted to DOH for review and approval before installation. The project report must include engineering calculations, a management plan, and a schedule for implementation.

— 7(c). CORROSION CONTROL DEMONSTRATION TESTING
If the recommendation is to conduct further evaluation of the alternatives in the form of demonstration testing, please indicate:

— 7(c-1). Treatments to be examined

— 7(c-2). Type of demonstration
- metal coupon tests (bench scale tests, electrochemical assessment)
- pipe rig/loop tests
- partial-system tests

— 7(c-3). Schedule for completion

If demonstration is to be conducted by an analogous system, provide justification of the analogous nature of the system (as in Step 3)

DOH will expect to receive and review a demonstration study report with final recommendations for treatment. If advance input is requested, the DOH reviewer will be available for comment on the protocol.

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Appendix C.
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	

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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	

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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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