City of Tacoma
Tacoma Public Utilities / Tacoma Water
Consultant Services for Gravity Pipeline Wells Improvement and Treatment
RFQ TW20-0227F

QUESTIONS and ANSWERS

All interested parties had the opportunity to submit questions in writing by email to Samol Hefley by September 15, 2020. The answers to the questions received are provided below and posted to the City's website at www.TacomaPurchasing.org: Navigate to *Current Contracting Opportunities* / *Services*, and then click *Questions and Answers* for this Specification. This information IS NOT considered an addendum. Respondents should consider this information when submitting their proposals.

Question 1: Per the RFP, on page 5 Tacoma Water states "Submittal Delivery" as being an electronic submission, however, on page 25 Tacoma Water states "Submit one (1) original copy of the SOQ containing original signatures and one (1) electronic copy on a USB flash drive. The hard copy shall be printed on standard paper and bound with a staple or binder clip." What is the preferred method of delivery for Tacoma Water?

Answer 1: Please see Addendum No. 1 posted on September 9, 2020. Electronic submission preferred method.

Question 2: Per the RFP, on page 25 Tacoma Water states "SOQs shall be limited to 30 pages total (equivalent to 15 pages printed front and back), not including appendices." Would tabs and/or a Table of Contents be counted toward the 30 page limit?

Answer 2: Tabs and Table of Contents will not be counted toward the 30 page limit

Question 3: Are we allowed to use 11 x 17 sheets, and if so do they count as one or two pages?

Answer 3: SOQ's may contain 11x17 pages where reasonable; each will count as one page.

Question 4: Is there a particular SBE form that should be used? If not, do we just answer the questions in 6.07 in the proposal?

Answer 4: There are no particular SBE form, please include responses to questions under section 6.07 in the responses to the RFQ.

Question 5: Could we please obtain a copy of the Corrosion Control Study Report that identified the need for corrosion control at the GPL wells?

Answer 5: Yes we can provide the Executive Summary from the Corrosion Control Assessment. Appendices will not be available.

Question 6: Would it be permissible to use an 11x17" page to better illustrate information (such as a schedule or site plan)? If so, would an 11x17" page count as one page or two pages?

Answer 6: SOQ's may contain 11x17 pages where reasonable; each will count as one page.

Executive Summary

The City of Tacoma Water Division (Tacoma Water) operates a regional drinking water system with a surface water source and multiple groundwater supplies. Tacoma Water has implemented multiple corrosion control measures over the past several years to control and minimize the corrosion and release of lead and copper in premise plumbing and remain fully compliant with the requirements of the federal Lead and Copper Rule (LCR). The measures the utility had taken on include:

1. Construction and use of corrosion control systems for the Green River and South Tacoma Wellfield supplies, the utility's two largest and most frequently used water supplies.
2. Removal and replacement of leaded brass appurtenances with non-leaded equivalents.
3. Providing free lead analysis in submitted water quality samples.
4. Locating and removing the remaining lead goosenecks in the distribution system.

The major emphasis has been lead, as Tacoma Water does not have any issues with respect to copper release in their system. Lead concentrations have always been below the regulatory 90th percentile action level (AL) of 15 μg/L in their LCR sampling data since 1995. Tacoma Water desired further reductions in lead concentrations to provide the highest level of public health protection and requested an evaluation of their current corrosion control processes. The evaluation included:

1. A background review of Tacoma Water's historical and current distribution water quality to correlate water quality conditions and LCR compliance,
2. A pipe loop test study to understand the fundamental interactions between Tacoma Water drinking water qualities and metals release,
3. Identifying future water quality parameters that Tacoma Water should operate with so its customers have even less potential lead exposure, and
4. Quantifying the construction and daily operating costs associated with these future water quality parameters.

This summary provides the major highlights for each of these tasks.

Background Review

The evaluation started with a combination of background literature and historical data review related to LCR compliance to identify trends that could further reduce lead corrosion, along with a review of operational practices to provide more information on the current pattern of lead release in Tacoma Water's system. The data review evaluated the impacts from operational practices/changes, system pH, system chlorine residual, and source of supply on LCR compliance. The findings on the effect of operational practices on LCR compliance are as follows:

- Installation of corrosion control processes on the Green River supply in 1997 has resulted in consistent compliance with LCR regulatory requirements.
- Although paired water quality parameters (WQP) and LCR compliance data are not available, 90th percentile and maximum lead levels appear to be reduced further when average systemwide pH levels are consistently above 7.5. When WQP samples pH falls below 7.5, 90th percentile lead levels have approached, but never exceeded, the 15 μg/L AL.
- Increasing the pH target at the Green River Filtration Facility (GRFF) over time from 7.5 to 8.2 has resulted in significant reduction in 90th percentile and maximum lead levels.

- The filtration of the Green River supply and elimination of all uncovered finished water storage reservoirs has resulted in continuous maintenance of chlorine residuals above 0.5 mg/L in the distribution system, with much more stable average residuals across the entire system. Stable chlorine residual is important for maintaining stable lead scales and reducing lead release into the water.

Pilot Pipe Loop Study

A pilot pipe loop study was performed to further understand the fundamental interactions between Tacoma Water's water qualities with copper piping, lead goosenecks, and meter setter brass piping and valving that could cause lead and copper release in premise plumbing. Test rigs were assembled at three locations in the distribution system (the Portland Avenue Reservoir, Hood Street Reservoir Inlet, and Hood Street Reservoir Outlet) with one of each of the three testing components (copper pipe, lead gooseneck, and brass meter, setter and valving) installed directly from Tacoma Water's distribution system and/or premise plumbing. Over the course of seven months, the test rigs were operated under conditions of 100 percent surface water, 100 percent groundwater, and various surface/groundwater blends.

The test loop results indicated very low copper release in copper plumbing and very low lead and copper release in leaded brass meter assemblies for all tested water quality conditions. The majority of lead release took place in the lead gooseneck components in which the majority of release was made up of particulate lead. Dissolved lead release was higher during periods of groundwater use than periods with solely Green River surface water, but adjusting the groundwater pH from 7.45 up to 7.8 provided little to no appreciable reduction in detected lead concentrations.

Future Water Quality Parameters

Following the data review and analysis of the pipe loop study data, water quality set point recommendations were developed to help achieve optimal corrosion control treatment throughout Tacoma Water's system. The recommended water quality set points are listed in Table ES-1.

Table ES-1. Recommended Water Quality and Operational Set Points

Source of Supply/Entry Point	Minimum Recommended pH and Alkalinity Set Point	Operational Set Points and Adjustment Method
Green River/North Fork Wellfield	pH 8.2 alkalinity 20mg/L as $CaCO_3$	pH 8.4 ± 0.2 using sodium hydroxide alkalinity 24 mg/L as $CaCO_3$ using existing sodium hydroxide and carbon dioxide feeds
Hood Street Reservoir	pH 7.4 no alkalinity set point	pH 7.6 ± 0.2 using sodium hydroxide
South Tacoma Pump Station	pH 7.4 no alkalinity set point	pH 7.4–7.6 using aeration
Other Wells	pH 7.4 no alkalinity set point	pH 7.6 ± 0.2 using sodium hydroxide or blending

The recommendations are developed through consideration of the current regulatory requirements as well as future revisions expected to place an increased focus on minimizing lead release. These minimum entry point set points were selected with the recognition that Tacoma Water has already done considerable work in minimizing lead corrosion and to minimize the impact of blending of different waters in the distribution system. Due to the variable levels of blending and resultant dissolved inorganic carbon

(DIC) levels, it is not meaningful to set distribution optimal water quality parameters (other than setting them based on the lower groundwater pH).

The study also recommends maintaining a target chlorine residual of 0.8 mg/L throughout the distribution system to maintain higher oxidation/reduction potential (ORP) conditions that favor the formation of lead scales [Pb(IV)] that are less likely to release lead into the water. The higher ORP conditions the system can maintain, the more likely Pb(IV) is formed, especially in the low DIC GRFF supply. Maintaining 0.8 mg/L throughout the distribution system means that chlorine dosages be increased to approximately 1.0 mg/L at the distribution system point of entry for each supply. An assessment of disinfection byproduct formation should be conducted if chlorine dosages are significantly increased. Furthermore, operational strategies are recommended that minimize the frequency and magnitude of DIC changes and Pb(IV) scale loss.

Recommended Improvements and Costs

Finally, the evaluation reviewed Tacoma Water's existing facilities and treatment set points to determine the magnitude of future chemical dosages and to prepare budgetary-level construction and daily chemical costs for each facility. Improvements at well facilities throughout Tacoma Water's service area include new chemical buildings for the addition of sodium hydroxide to raise groundwater pH levels to meet the recommended future water quality parameters. Other upgrades include new chemical feed systems, replacement of existing, inadequate buildings, and upgrades to electrical and instrumentation and controls.

Table ES-2. Recommended Corrosion Control Improvements and Associated Construction Cost Estimates

Facility	Major Capital Improvements	Estimated Construction Cost	Estimated Additional Daily Chemical Cost
Green River and North Fork Wellfield	No capital improvements are needed.	-	$400
South Tacoma Wellfield	No capital improvements are needed.	-	-
Prairie Ridge Springs	Replace existing chlorine building with larger building for sodium hydroxide and chlorine storage and feed.	$557,000	$41
Wells GPL1 and GPL2	Construct new building to supply sodium hydroxide to both wells.	$1,099,000	$474
Wells SE11/SE11A	Construct new building to supply sodium hydroxide to both wells and replace existing substandard piping.	$529,000	$109
Well SE8	Construct new building to supply sodium hydroxide to the well.	$169,000	$75
Wells SE2/SE6	Remove and replace existing sodium hydroxide storage tank and feed system, replace existing substandard piping, and upgrade existing chlorination system.	$384,000	$108
Portland Avenue Well	No capital improvements are needed at this well if blending is implemented. Otherwise, construct a packed tower aeration system.	$1,038,000 if aeration is required	No chemicals required for blending or aeration

Facility	Major Capital Improvements	Estimated Construction Cost	Estimated Additional Daily Chemical Cost
Well UP1	Construct new building to supply sodium hydroxide to the well.	$382,000	$84

Notes:

1. All construction and daily chemical costs estimated in December 2017.
2. Estimated additional daily costs assume continuous operations at peak well supply.
3. Estimated additional chemical costs for the Green River and North Fork Wellfield include sodium hydroxide and CO_2.
4. Estimated additional daily chemical costs for all wells include sodium hydroxide and sodium hypochlorite.

1 Project Introduction and Purpose

Tacoma Water owns and operates a regional Group A drinking water system with a combination of surface and groundwater supplies that serves over 300,000 customers and a number of independent water systems in King and Pierce Counties. Tacoma Water is regulated by the Washington Department of Health (DOH) through Washington Administrative Code Chapter 246-290, which stipulates the requirements to comply with the Safe Drinking Water Act (SDWA). In 1991, the US Environmental Protection Agency (EPA) published a regulation to control lead and copper in drinking water, the Lead and Copper Rule (LCR), as part of the SDWA. The rule established a maximum contaminant level goal (MCLG) of zero for lead in drinking water and a treatment technique to reduce corrosion of lead and copper within the distribution system. Under the LCR, utilities are required to monitor drinking water at the source, in distribution, and at customer taps. If lead exceeds the AL of 15 μg/L and/or copper exceeds the AL of 1.3 mg/L at the 90th percentile of all samples drawn from customer taps, the utility is required to take a number of actions to control corrosion throughout their system.

Tacoma Water has implemented multiple corrosion control measures over the past several years to control corrosion and release of lead and copper in premise plumbing to remain in compliance with the LCR and to reduce lead exposure. Tacoma Water has constructed corrosion control treatment (CCT) at their largest water supplies. To further reduce public health exposure to lead, Tacoma Water has been removing all lead goosenecks throughout their system when they are encountered during the galvanized iron service line replacement and water main programs. In addition, Tacoma Water has never allowed lead service lines to be installed and none are known to exist in the system.

The lead-related water quality events at Flint, Michigan, have caused Tacoma Water to reexamine its LCR compliance activities and to reaffirm its commitment to further reduce the exposure of lead to its customers. In addition, Tacoma Water has implemented corrosion control treatment at the GRFF and the South Tacoma Wellfield, its two largest and most used water supplies, but many of the smaller groundwater supplies still lack such treatment. While these other supplies are very infrequently used, Tacoma Water wishes to define the required treatment at each location so that they can be upgraded when these supplies are used more frequently in the future. Finally, the newly constructed GRFF provides additional corrosion control treatment processes (i.e., alkalinity adjustment) that were lacking prior to 2014. Tacoma Water wishes to know what is the most appropriate treated water pH and alkalinity for this facility.

HDR Engineering, Inc., (HDR) was hired to assist in this reexamination. The specific tasks conducted for this effort are as follows:

1. Task 200 – Reviewing Tacoma Water’s historical and current distribution water quality.
2. Task 300 – Pilot testing of various premise plumbing components with varying surface water and groundwaters.
3. Task 400 – Evaluating future water quality set points with respect to controlling and minimizing lead release in distribution systems.
4. Task 500 – Identifying operational practices and/or capital improvements that the utility can implement to reach the water quality set points.

The results of Tasks 200 through 500 are written up as separate documents attached this report. This report is Task 600 and provides a summary of the other documents. (Task 100 was HDR’s project management task and is not included).

2 Water System Supplies and Associated Treatment

Tacoma Water's primary source of supply is the Green River. This supply is treated using ozonation, direct/conventional filtration, fluoridation, alkalinity management with carbon dioxide, pH adjustment with sodium hydroxide, and sodium hypochlorite disinfection at the 150 million gallons per day (MGD) GRFF. The North Fork wells are co-located with the Green River supply, treated through the same processes, and share a water right and watershed with the Green River surface water source.

Tacoma Water's remaining groundwater supplies are referred to as "in-town wells" because they are located throughout the city. These supplies are used for a variety of purposes, such as meeting demands when the Green River is not available or at reduced capacity due to high turbidities, during droughts, for emergency responses, and to balance water supplies within the regional transmission and distribution system. The in-town wells include 24 active and two emergency groundwater sources, the largest of which is the 45 MGD South Tacoma Wellfield. The overall wells supply approximately 7 percent of the system's annual water demand and are capable of supplying a rate of over 60 MGD. The South Tacoma Wellfield groundwater is chlorinated and pH adjusted using either sodium hydroxide or aeration for LCR compliance purposes while the Wells SE2 and SE6 are dosed with both sodium hypochlorite and sodium hydroxide; the remainder of the wells has no other treatment other than chlorination. Table 1 summarizes the treatment capacity and processes for each water source.

Table 1. Summary of Water Supplies

Source Designation/Capacity	Well Nos.[1]	Treated Capacity (MGD)	Treatment
Green River Filtration Facility	-	150	Ozonation, direct/conventional filtration, sodium hydroxide, 12.5% sodium hypochlorite, fluoridation
North Fork Wellfield	-	84	Blended with Green River water prior to all other treatment processes at the GRFF.
Gravity Wells	1, 2	8	12.5% sodium hypochlorite
South Tacoma Wellfield	1B, 2B, 2C, 3A, 4A, 5A, 6B, 7B, 8B, 9A, 10C, 11A, 12A, 13A	48	On-site 0.8% hypochlorite generation, sodium hydroxide, and fluoridation at Hood Street Reservoir (12A receives aeration for VOC removal which also adjusts the pH). Wells 1B, 3A, 7B, 8B, 10C, and 13A can be also treated at South Tacoma PS using calcium hypochlorite and diffused aeration.
Southeast Tacoma Wells	SE2, SE6	1.2	12.5% sodium hypochlorite, sodium hydroxide
	SE8	0.7	12.5% sodium hypochlorite
	SE11, SE11A	2.0	12.5% sodium hypochlorite
University Place Wellfield	UP1, (10U)	1.6 (+1.0 emergency)	12.5% sodium hypochlorite
Tideflats Well		1.0 (emergency)	None
Portland Avenue Well		1.7	Blended with treated water from Green River, North Fork Wellfield, and Gravity Wells for arsenic reduction
Prairie Ridge Springs		0.8	12.5% sodium hypochlorite

[1]Emergency wells denoted in parentheses.

3 Task 200 – Historical and Current Water Quality

Tacoma Water began corrosion control treatment of their major Green River supply in 1997 by increasing the pH to a minimum of 7.5 using sodium hydroxide. Corrosion control processes, consisting of sodium hydroxide pH adjustment, initially began at the 214th Street Corrosion Control Facility. These processes were relocated to the Green River Headworks Chemical Facility in 2005, and then continued at the GRFF when it was constructed and placed online in 2014. The set point for finished water pH was increased to 8.2 in February 2016 in response to local and national concerns related to lead corrosion. Tacoma Water operates under a DOH-designated WQP of a minimum pH of 7.5 established for the Green River supply. This pH value was established in 1998 and yet to be updated when the GRFF became operational.

Adjustment of the pH for Tacoma Water's major secondary supply, the South Tacoma Wellfield, started in 2014 and includes diffused aeration inside the South Tacoma Pump Station and sodium hydroxide feed to the inlet to the Hood Street Reservoir. These corrosion control systems are designed to increase the South Tacoma groundwater pH to 7.5 +/- 0.2. The varying pH and alkalinity for individual wells, and site-specific transient hydraulic conditions, can cause the adjusted water pH to fluctuate. There is no DOH-designated WQP for any of the groundwater supplies.

3.1 Operational Practices for LCR Compliance

The full history of LCR compliance data was reviewed, including lead and copper sampling results (1992 to 2016) and water quality parameter monitoring (1997 to 2016), and compared against LCR compliance data to identify impacts from groundwater usage, corrosion control treatment changes, distribution system pH, and distribution system chlorine residual. This section presents a summary of the review, with the full evaluation of historical data located in the Task 200 report in Appendix A.

Table 2 provides the historical raw water pH and alkalinity for each of Tacoma Water's water supplies. This data is from the annual inorganic contaminant monitoring required for regulatory reporting. According to Tacoma Water, the North Fork Wellfield water quality mimics the pH and alkalinity of the adjacent Green River surface water as they are in the same watershed and are hydraulically connected. Both sources are low in alkalinity, ranging from 13 to 27 mg/L as $CaCO_3$. These sources are treated through the GRFF and adjusted to a finished water pH of 8.0–8.4 using sodium hydroxide. The addition of sodium hydroxide boosts the alkalinity to a finished water concentration of approximately 20 mg/L as $CaCO_3$. The pH of all of the groundwater sources averages slightly over 7.0, with alkalinities typically exceeding 80 mg/L as $CaCO_3$.

Table 2. Historical Raw Water pH and Alkalinity from 2000 – 2016

Supply	pH (mean and range)	Alkalinity (as CaCO3) (mean and range)
Green River and North Fork Supplies		
Green River[1,2]	7.6 (6.8 – 7.9)	18 (13 – 27)
North Fork Wells	7.0 (6.6 – 7.6)	16 (13 - 19)
South Tacoma Wellfield		
Well 1B	7.2 (6.9 - 7.5)	83 (80 - 84)
Well 2B	6.9 (6.8 - 7.1)	115 (110 - 120)
Well 2C	7.4 (7.4 - 7.5)	69 (69 - 70)
Well 3A	7.1 (6.7 - 7.4)	81 (72 - 92)
Well 4A	6.9 (6.6 - 7.2)	104 (93 - 111)
Well 5A	7.0 (6.7 - 7.4)	81 (76 - 86)
Well 6B	7.1 (6.7 - 7.3)	74 (69 - 82)
Well 7B	7.0 (6.6 - 7.5)	65 (60 - 74)
Well 8B	7.2 (6.6 - 7.5)	82 (75 - 88)
Well 9A	6.7 (6.7 – 6.7)	86 (69 - 104)
Well 10C	7.0 (6.9 - 7.2)	91 (74 - 109)
Well 11A	7.0 (6.9 - 7.2)	81 (67 - 93)
Well 12A	7.2 (6.7 - 8.3)	130 (110 - 142)
Well 13A	7.4 (7.0 - 7.9)	58 (56 - 60)
SE Tacoma Wells		
Well SE2/SE6	6.8 (6.4 - 7.2)	56 (52 - 62)
Well SE8	7.0 (6.7 - 7.6)	77 (70 - 80)
Well SE11/SE11A	7.1 (6.7 - 7.4)	65 (33 - 77)
Other In-Town Well Supplies		
Well GPL1	7.1 (6.7 - 7.5)	82 (74 - 89)
Well GPL2	7.0 (6.5 - 7.2)	81 (72 - 89)
Well UP1	7.2 (6.9 - 7.6)	77 (70 - 84)
Portland Ave Well	7.2 (6.7 - 8.1)	61 (59 - 65)
Prairie Ridge Springs	7.4 (7.1 - 7.6)	101 (98 - 105)

[1]Raw water pH data for Green River source is for April 2015–September 2016
[2]Raw water alkalinity data for Green River source is from November 2015–February 2017

3.2 Data Review

3.2.1 LCR Data Review

Figure 1 presents the average, median, 90th percentile, and maximum concentrations from 1992 (the first year of LCR monitoring) through August 2016 for detected lead concentrations in compliance samples.

Two rounds of approximately 100 samples each were collected in June and October of 1992, with the first round exceeding the lead AL. Tacoma Water collected a minimum of 100 samples for LCR testing approximately every six months from 1995 through 2000. Beginning in 2001, LCR monitoring was reduced to an annual interval, and reduced again to every three years after 2004. The most recent round of LCR samples was collected in July 2016.

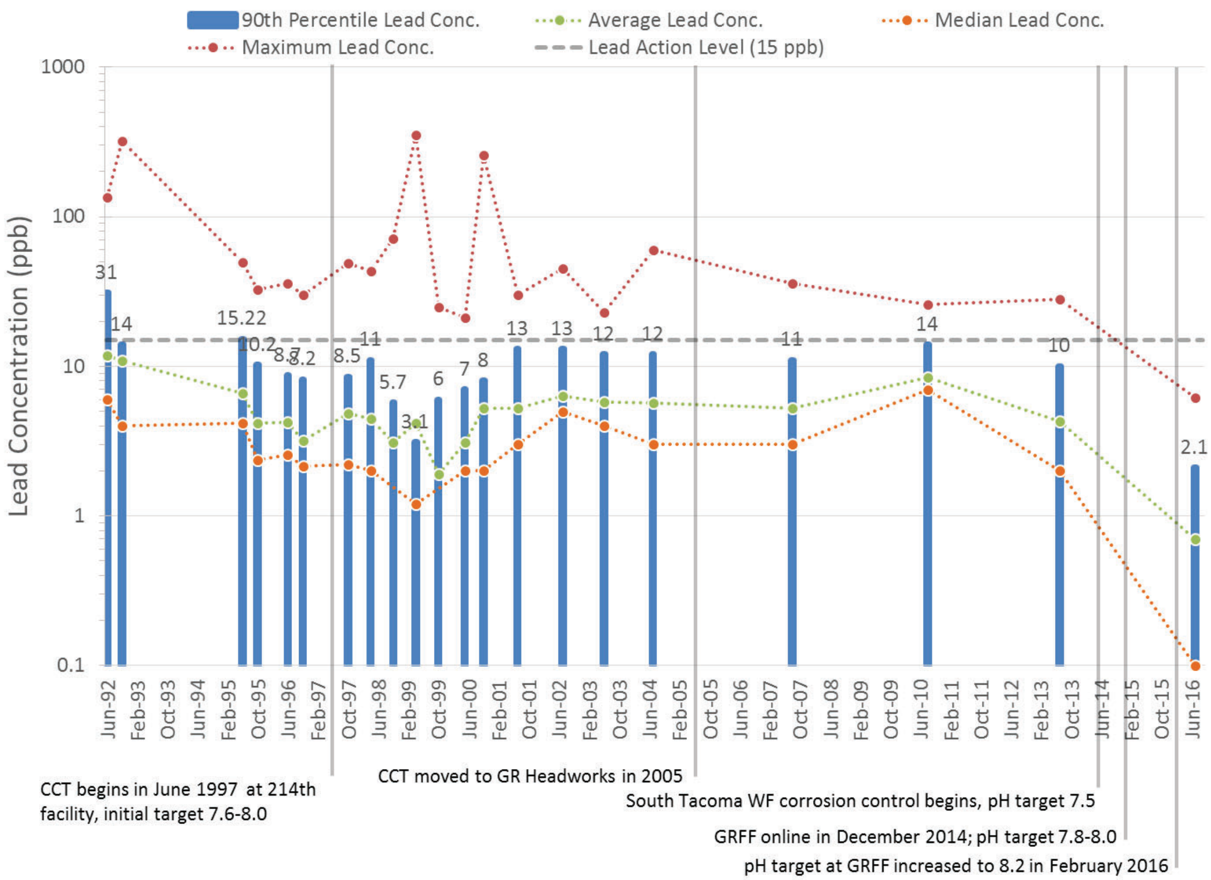


Figure 1. Historical LCR Lead Concentrations

Historically, Tacoma Water treated water has caused lead concentrations detected in LCR compliance sampling at customer premise plumbing to be near, but not exceed, the 15 µg/L AL. Recently, the reduction in lead concentrations observed in 2016 can be attributed to the start-up of the GRFF and increase of the pH target from 7.6–8.0 to 8.2.

Copper concentrations exceeded the 1.3 mg/L AL during the two initial LCR rounds in 1992 and again in 1996 (data not shown here but found in Appendix A report). As with lead, there has been no exceedance of the copper AL since corrosion control started in 1997. Unlike lead, copper concentrations in LCR compliance sampling after 1996 have been considerably lower than AL. Thusly, Tacoma Water has placed a lower emphasis for reducing copper corrosion compared to lead corrosion.

Lead corrosion is influenced by chemical, physical, and/or biological conditions, and lead can occur in the dissolved and/or particulate form. Median, average, and maximum lead concentrations shown in Figure 1 are an attempt to understand the nature of lead spikes, given that compliance samples were not speciated to distinguish between dissolved and particulate fractions. The LCR treatment strategies focus on lead release caused by uniform corrosion that can be mitigated by optimizing water chemistry. The spikes in lead maximum concentrations seen in 1999 and in 2000 appear to be related to particulate lead release in individual samples, rather than excessive uniform corrosion within the distribution system. For example, during the 1999 sampling event, the 90th percentile was only 3.1 μg/L, and the median was just above 1 μg/L, despite an extreme maximum result of approximately 400 μg/L. Typically, such large differences between the 90th percentile and the maximum results are caused by the release of particulate lead. While some amount of lead release can be expected in the particulate form, the reduction in lead concentrations following implementation of corrosion control in 1997 and further reduction in 2016 after the GRFF finished water pH was increased to 8.2 suggests that lead release from premise plumbing corrosion can be sufficiently controlled by increasing the supplied drinking water pH.

3.2.2 LCR Water Quality Parameters

In addition to lead (and copper) sampling, Tacoma Water has monitored alkalinity and pH throughout the distribution system at multiple locations semiannually through 2002 and annually afterwards as part of the utility's LCR WQP monitoring. Figure 2 compares WQP data with the percentage of water supplied by groundwater from in-town wells. Groundwater usage during periods of WQP sampling is evidenced by increases in the amount and variability in alkalinity levels. Unfortunately, WQP monitoring is not required to be coordinated on the same day or the same week that residential LCR sample collection is performed, nor can WQPs be measured directly from LCR compliance samples, so a direct relationship between lead data and WQP data cannot be established.

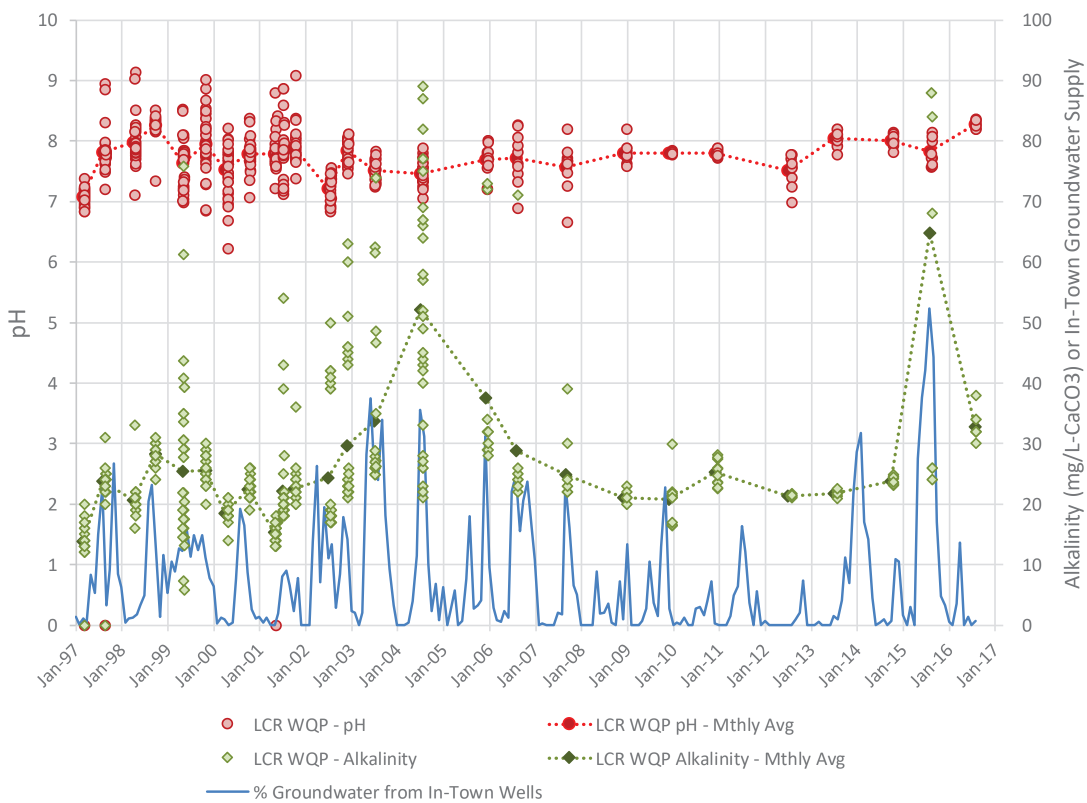


Figure 2. Historical Water Quality Parameters vs. Groundwater

Despite the inability to establish this direct relationship, the WQP data does provide very useful data that informs what lead release concentrations could be in the Tacoma Water's customer premise plumbing.

Distribution system pH variability decreased over time as capital improvements were implemented, including covering several open-air reservoirs, filtration of the Green River supply, and corrosion control of the South Tacoma Wellfield. These improvements have contributed to increased pH stability in the distribution system. While excursions still occur, Tacoma Water has generally maintained a pH of 7.5 or greater in distribution system WQP measurements, including the past four continuous years.

3.2.3 Distribution Grab Sample and Online Water Quality Data

In addition to the LCR WQP monitoring, Tacoma Water also monitors pH and chlorine in grab samples collected during routine Total Coliform Rule monitoring, and also at several booster pump stations and reservoirs in the distribution system using online instrumentation. This pH and chlorine residual data is discussed in Appendix A to fully document trends in distribution system pH and free chlorine levels.

The review found that chlorine residuals in the Tacoma Water system have slowly improved over the years with the covering of the open-air reservoirs, and increased considerably once the Green River supply began to be filtered by the GRFF. Average and minimum chlorine residuals in the distribution system have increased since 2006 and corresponding heterotrophic plate counts have been consistently at or close to zero. In addition, seasonal chlorine residual drops in the fall—related to turbidity events during annual Howard Hanson Dam releases—appear to be largely mitigated by the GRFF. The result is that chlorine residual has been consistently maintained above 0.5 mg/L in system samples since filtration was installed. As will be noted later, chlorine residual maintenance needs to be a key part of Tacoma Water's corrosion control strategy.

3.3 Summary of Findings

The comprehensive review of the historical and current water quality data determined the following LCR-related findings.

- Installation of corrosion control on the Green River supply in 1997 has resulted in consistent compliance with LCR, as defined as >90 percent of samples below the lead (and copper) AL.
- Although paired WQP and LCR lead data could not be determined, 90th percentile and maximum lead concentrations appear to be reduced when average system-wide pH levels are consistently above 7.5. When WQP samples show pH below 7.5, 90th percentile lead concentrations have approached, but never exceeded, the 15 µg/L lead AL. The vast majority of water in the distribution system has always been the Green River water, except during the 2015 drought.
- LCR samples have not been collected during periods of groundwater usage ever since pH adjustment of the South Tacoma groundwater supply was initiated.
- Increasing the GRFF pH target from 7.5 to 8.2 resulted in significant reduction in 90th percentile and maximum lead concentrations as evidenced by the 2016 LCR sampling.
- Green River filtration and elimination of uncovered finished water storage has resulted in maintenance of chlorine residuals above 0.5 mg/L throughout the distribution system, with much more stable average residuals across the system. Stable chlorine residual is important for maintaining stable lead scales.
  - Samples with lead concentrations above the AL had a very weak correlation, if any, with localized pH levels or periods of groundwater use. However, as discussed previously, no paired pH and lead data are available.
  - The most significant reductions in 90th percentile lead levels were observed when the GRFF target was increased to 8.2.

4 Task 300 – Pilot Testing and Scaling Analysis

In parallel to the Task 200 water quality review, Tacoma Water conducted a pipe loop study to:

- Determine the impact of surface water versus groundwater quality on lead (and copper) release from these components,
- Determine lead contributions from various lead-containing components, and
- Assess the composition of the lead scale layers formed on the interior of these components and quantify their impact.

Test rigs were assembled at three locations: the Portland Avenue Reservoir (PAR), Hood Street Reservoir (HSR) Inlet, and HSR Outlet. Test rigs at the PAR site received surface water throughout the entire testing period. HSR Inlet test rig water supply sources were switched from 100 percent Green River surface water to 100 percent South Tacoma groundwater between phases while the HSR Outlet test rig received blends of surface water and groundwater. Each test rig contained a copper pipe segment, a lead gooseneck, and a leaded brass meter and meter assembly. Each of these components was removed from Tacoma Water's distribution system and/or premise plumbing and had been in active service for many decades. As a result, these components were representative of the inventory of aging components still installed throughout the Tacoma Water distribution system and in it's customer premise plumbing.

Over the course of seven months, the test rigs were operated under conditions of surface water, groundwater and surface/groundwater blends. Pipe loop components were removed from test rigs for scale analysis after the first two phases of testing and at the conclusion of testing for scale analysis.

Figure 3 shows the lead concentrations from the PAR Outlet Building lead gooseneck. This gooseneck, being constantly supplied by Green River water, showed that lead release was generally between 10 to 20 μg/L, with significant fractions of the released lead being particulate. Figure 4 shows the lead and copper concentrations from the leaded brass meter and meter assembly. The major point is that the leaded brass exhibited very little lead and copper release.

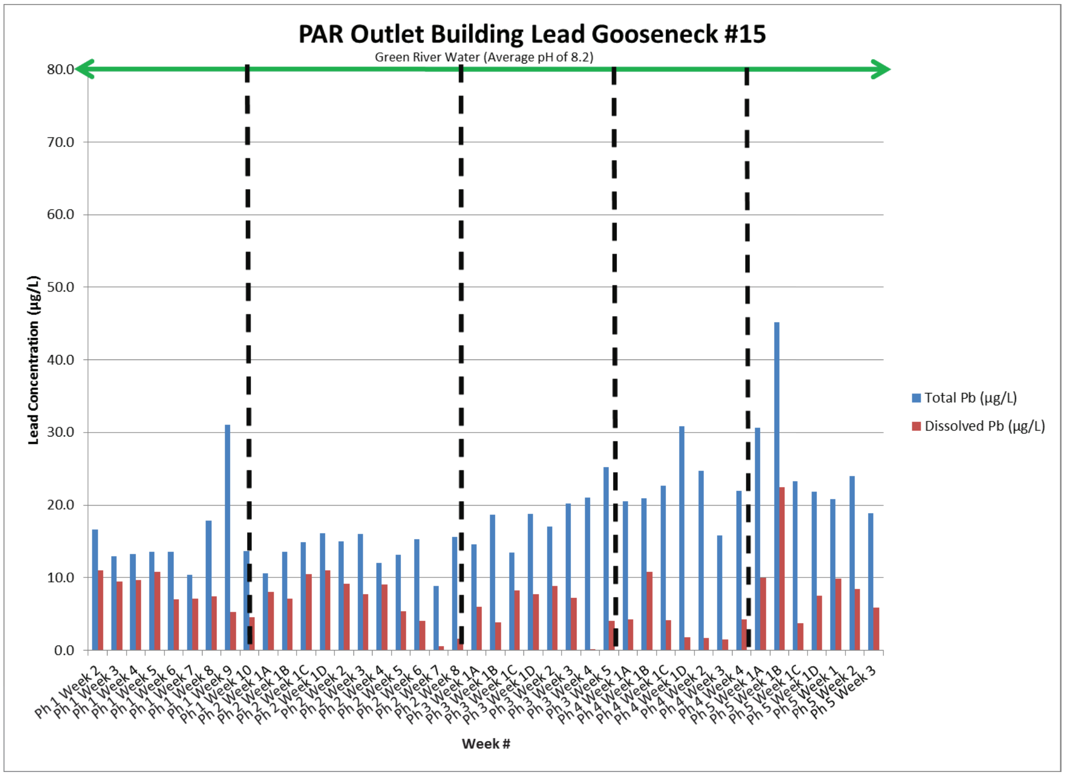


Figure 3. Lead Concentrations for Lead Gooseneck at Portland Avenue Reservoir

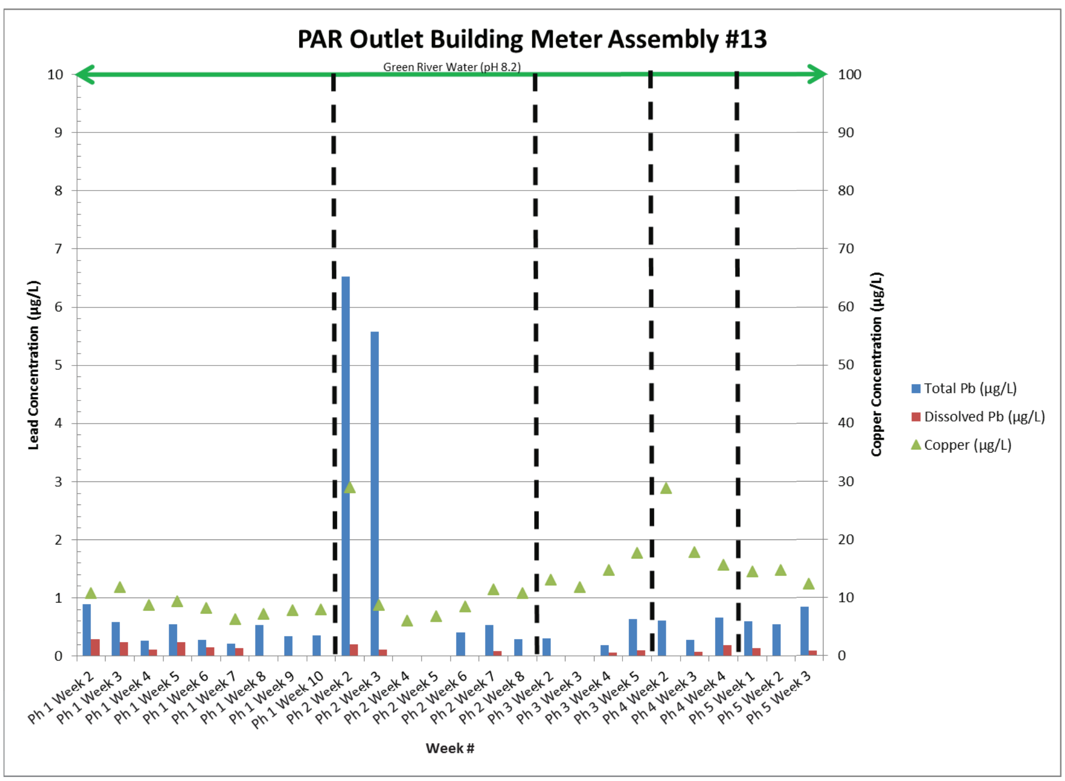


Figure 4. Lead and Copper Concentrations for Meter Assembly at Portland Avenue Reservoir

In comparison, the lead gooseneck shown in the Figure 5 shows that switching between the water supplies caused lead release to occur. In this example, switching from a target pH 8.2 Green River to target pH 7.45 groundwater caused lead release to increase four-fold immediately but continued exposure to the groundwater allowed the scales to begin restabilizing such that lead concentrations in the samples at the end of the first groundwater exposure were more than half of those at the beginning of groundwater exposure. Transitioning back to the Green River supply caused an immediate lead decrease in both total and dissolved lead followed by lead concentrations matching or slightly higher than the first Green River exposure period, and also similar to the some of results from the target pH 7.45 groundwater period. Particulate lead was not significantly different from the prior groundwater period. The final transition to target pH 7.8 groundwater caused another initial high lead release. The subsequent total lead concentrations were similar to the Green River exposure periods, however, in this period, much of the lead release was dissolved as opposed to particulate lead. Note that the target pH is the pH of the water entering the test rigs, not the pH of the water sample.

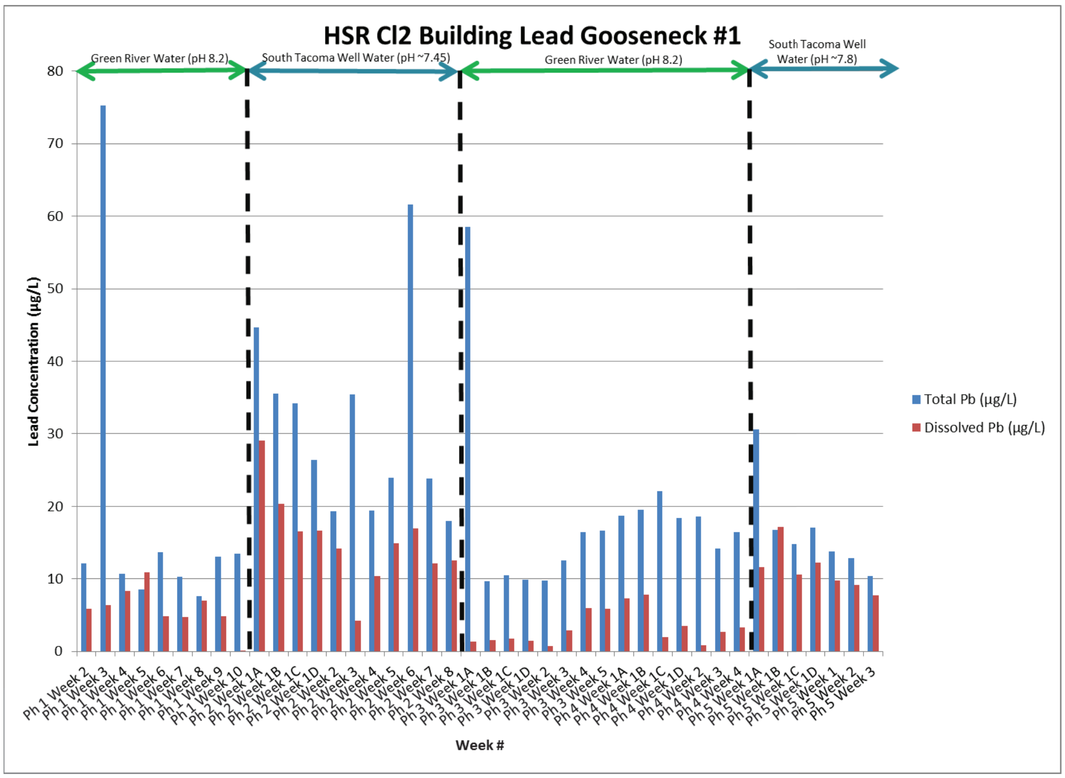


Figure 5. Lead Gooseneck at HSR Inlet

The full test plan and report are found in Appendix B, which also includes discussion of the other test components at the PAR, HSR Inlet, and HSR Outlet. While the one example in Figure 5 would indicate that target pH 7.8 groundwater results in less lead release than a target pH 7.45 groundwater, plotting the measured pH for all lead samples for every test component for the duration of the testing reveals a different picture. Figure 6 shows this correlation with dissolved lead. The pH drifts in stagnation and accounting for this drift indicates that the actual reduction in lead release is very small, if at all. Figure 7 shows a plot of particulate lead versus pH. As expected, there is no correlation but this data and the prior figures show particulate lead is at least equal, or sometimes the majority contributor to lead release.

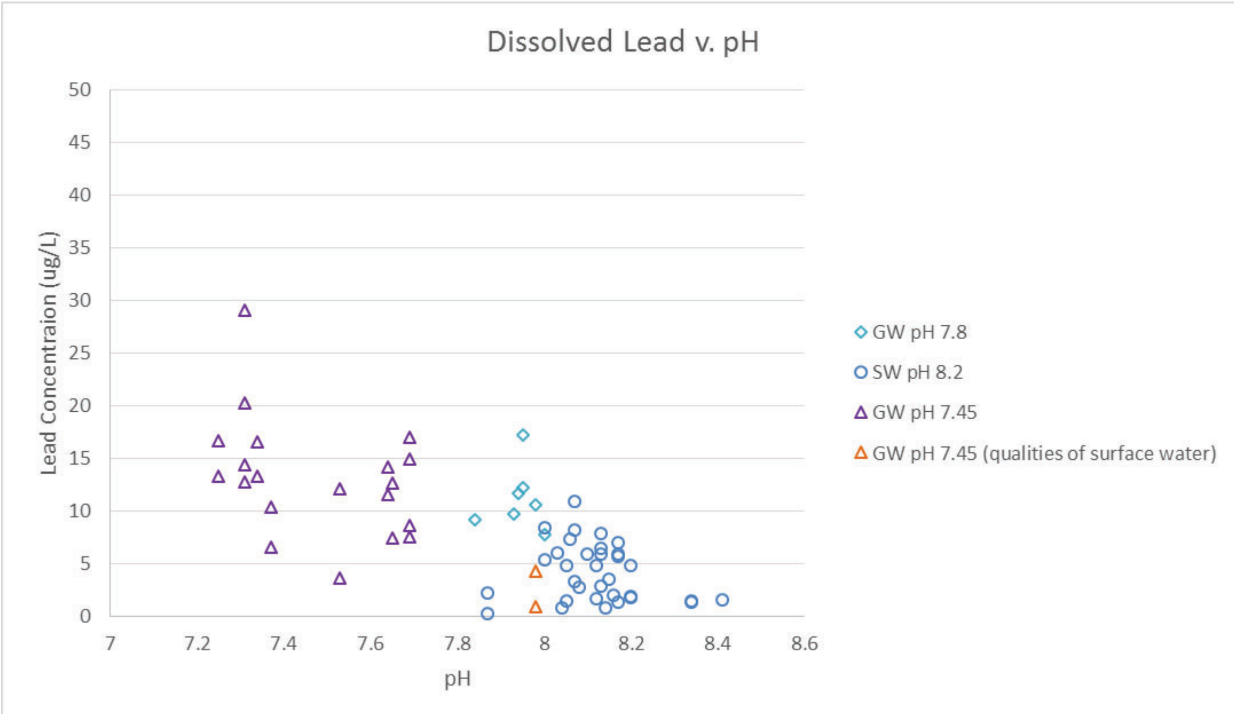


Figure 6. pH and Dissolved Lead Correlation for Lead Gooseneck Components at HSR Inlet.

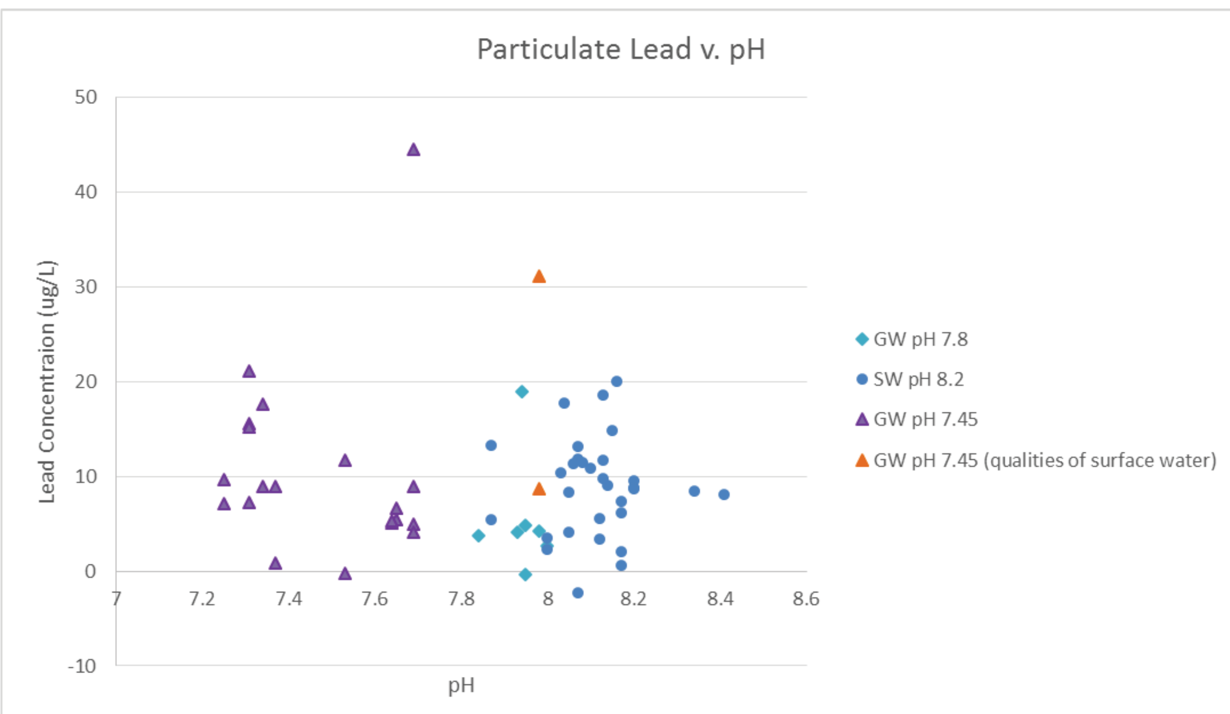


Figure 7. pH and Particulate Lead Correlation for Lead Gooseneck Components at HSR Inlet.

Finally, comparing dissolved lead concentrations with DIC again shows the lack of reduction with increasing groundwater pH (see Figure 8). The results for pH 7.45 and pH 7.8 groundwater essentially overlap, thus showing that using additional sodium hydroxide to increase water pH provided no benefit.

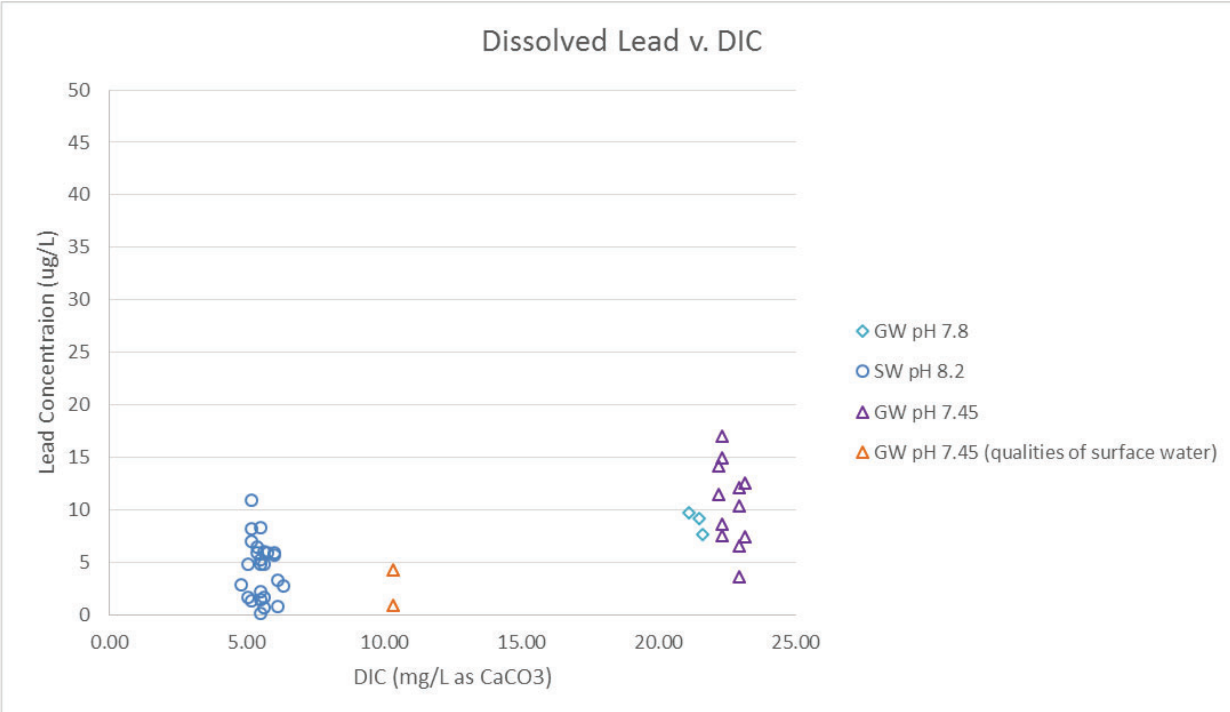


Figure 8. DIC and Dissolved Lead Correlation for Lead Gooseneck Components at HSR Inlet

The pilot study summary conclusions are as follows:

1. The lead goosenecks that Tacoma Water is actively removing from the system release an appreciable amount of lead if they remain in service, though they are unlikely to affect LCR compliance as homes with lead goosenecks are unlikely to be classified as Tier 1 sample sites under the current LCR.
2. The leaded brass meters the utility still has in place (but is no longer installing) release orders of magnitude less lead than the goosenecks and do not appear to impact LCR compliance.
3. Particulate lead was a significant portion of the total lead measured from the gooseneck test components.
4. Release of copper from the leaded brass and copper plumbing was found to be negligible throughout all testing, which confirmed Tacoma Water historical compliance data.
5. Water quality had little to no impact on copper release from copper piping components.
6. Lead release was higher in the high DIC groundwater compared to the low DIC surface water.
7. Under high ORP (i.e. chlorinated) conditions, Green River water can likely form Pb(IV) scale that is better for reducing lead corrosion than Pb(II) scales. Hydrocerrusite is a more stable lead mineral, and less likely to release lead into drinking water compared to cerrusite.
8. The chloride-sulfate mass ratio (CSMR) was calculated but provided no value in identifying issues and solutions for reducing lead release from Tacoma Water’s leaded components. No impact could be determined by changes in the CSMR, especially in light of the much greater impact of pH, alkalinity, and ORP.

The scale analyses also identified the following major conclusions regarding the nature and extent of changes to the wetted surfaces caused by the transition from Green River water to a Green River/groundwater blend and groundwater only.

4.1.1 Copper Pipe

1. The surface of exposed copper pipe is in all cases dominated by morphologically nondescript scales associated with a cuprous oxide substrate and superficial more disperse malachite.
2. Short-term transition from the surface water to groundwater appears to interfere with the deposition of malachite while the cuprous oxide films do not undergo any notable changes.

4.1.2 Leaded Brass Water Meter Assemblies

1. Surfaces of bronze water meters do not present any distinct morphologies. The scales are non-uniform and dominated by disperse coalesced and co-deposited formations.
2. Transition from surface water per se to its blend and groundwater only do not cause any specific types of surface scales to appear on the wetted surfaces of the meters but these scales become somewhat more compact.

4.1.3 Lead Goosenecks

1. Properties of scales formed on the surface of lead goosenecks (and their brass connectors) depend greatly on the distance from the gooseneck's entry point (its brass connector) to medial areas of the specimen.
2. There were no visually discernible signs of accelerated metal loss or other modes of localized corrosion attack located in the galvanic junction areas of the examined goosenecks. In other words, galvanic corrosion does not appear in the analyzed specimens.
3. The surface of lead pipe per se exposed to the treated surface water was clearly dominated by the extensive deposition of relatively large platy crystals of Pb(II) and dispersed smaller particles of Pb(IV). This mode of the formation of surface scales is typical for relatively low alkalinity waters in the presence of chlorine disinfectant.
    - These observations are in agreement with prior research showing that hydrocerussite and, at higher alkalinities, cerussite are dominant; frequently coexisting solid phases formed as a result of the corrosion of lead in drinking water.
    - Prior research has demonstrated that in drinking water, lead dioxide is formed via the oxidation of hydrocerussite and cerussite by chlorine. Morphologically, lead dioxide formed in drinking water conditions is present as very small particles that tend to be interspersed with cerussite and hydrocerussite, as observed in this study.
4. The transition from Green River water to a Green River/groundwater blend somewhat increased the prevalence of cerussite-like formations. The surface of lead pipe in the medial area of the examined gooseneck specimens remained dominated by hydrocerussite and lead dioxide albeit the crystals of hydrocerussite became smaller than those observed for exposures to the surface water only.
5. Short-term transitions for water chemistry from Green River to only groundwater suppressed the formation of hydrocerussite (the more stable lead mineral) and notably enhanced the deposition of cerussite (the more unstable mineral prone to release lead). This is in agreement with the predictions made based on relevant water chemistry calculations.
6. A similar trend was observed in exposures to groundwater only. There was some enhancement of the formation of cerussite but large areas of the examined gooseneck retained the morphological dominance of hydrocerussite and lead dioxide.

- Given the typical coexistence of cerussite and hydrocerussite, the prevalence of cerussite over hydrocerussite, or vice versa, is not necessarily indicative of major changes of lead release, especially in the presence of chlorine that drives the oxidation of these solids to lead dioxide whose presence is critical for controlling lead release.

7. Scanning electron microscopy shows the occurrence of lead dioxide microcrystals on the surfaces of all examined lead goosenecks. In terms of practical aspects of lead control in Tacoma drinking water, the consistent presence of lead dioxide whose equilibrium solubility is practically zero for the water qualities examined in this study is indicative of the continuing suppression of lead release caused by the action of free chlorine.

8. Transient changes of water chemistry, for instance short-term increases of its alkalinity followed by its decrease to the corresponding background level, can affect the stability of Pb(II) and Pb(IV) phases because such changes do cause crystals of one phase (e.g., hydrocerussite) to transform to those of the other (e.g., cerussite) and vice versa. These transitions can also be accompanied by changes of the processes of the oxidation of Pb(II) phases to lead dioxide. Such continuing cycles can potentially cause transient changes of lead release but the continuing presence of free chlorine and the oxidation of Pb(II) solids by this it is expected to result in the leveling-off of such transients.

5 Task 400 – Proposed Water Quality Set Points

Task 400 combined the data obtained from the Task 200 background review with the Task 300 pilot testing information and drinking water industry's state-of-the-science understanding with respect to controlling lead release in premise plumbing to determine what adjustments may be required for the Tacoma Water water quality.

5.1 Optimized Corrosion Control Treatment Strategies

When the LCR was first promulgated in 1991, optimal CCT (OCCT) strategies included:

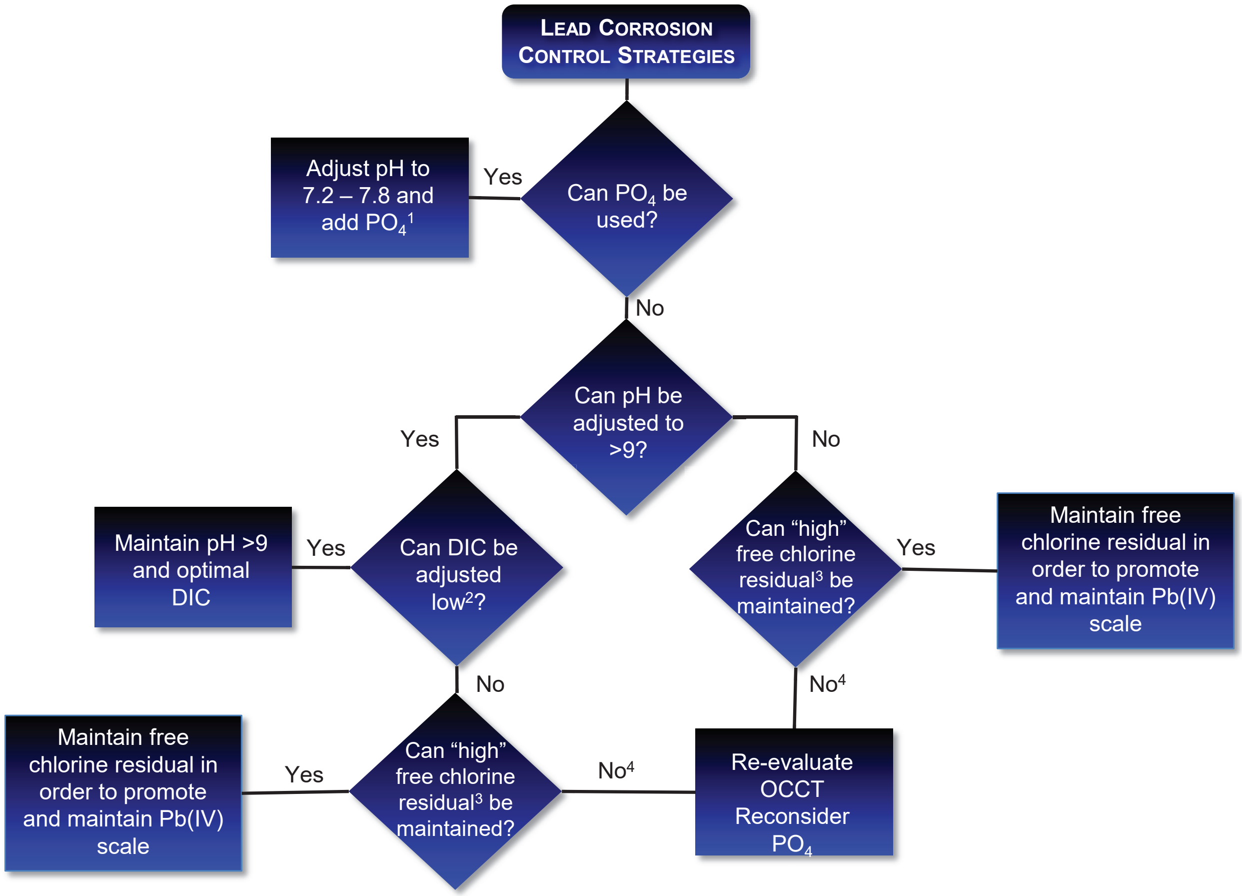
1. Passivation through pH/alkalinity adjustment
2. Passivation through use of phosphate- or silicate-based inhibitors
3. Calcium carbonate precipitation

Over the past 25 years, industry understanding of OCCT has advanced into the following:

1. Passivation through pH/alkalinity adjustment
2. Passivation through use of phosphate- or silicate-based inhibitors
3. Formation of a Pb(IV) scale through maintenance of a high free chlorine residual

The key changes in OCCT involve recognition that the solubility design basis should be broadened beyond just Pb(II) species (e.g., cerrusite, hydrocerrusite) and also include Pb(IV) (e.g., lead dioxide). The need to address particulate lead in addition to dissolved lead has also come to the forefront, although OCCT primarily addresses dissolved lead as discussed further below. The relative ineffectiveness of calcium carbonate precipitation for control of lead (and copper) release has also been recognized. Other, newer areas of understanding involve the importance of ORP, largely controlled by secondary disinfectant type and residual, in formation of Pb(IV) scales, iron release, manganese release, and co-occurring lead present in iron and manganese-rich scales. The role of microbial induced corrosion can also be an important factor contributing to metals release in distribution systems and premise plumbing (AWWA M58 2017).

Current industry thinking regarding OCCT is summarized in Figure 9. The following sections summarize newer considerations associated with pH/alkalinity adjustment as applicable to Tacoma Water's current conditions.



[1]Higher pH may be acceptable; [2]Typically < 10–20 mg/L as C, but depends on site-specific conditions; [3]A high free chlorine (Cl_2) residual may require a concentration of 1 mg/L as Cl_2 or higher throughout the distribution system, depending on local conditions (e.g., water quality, type and age of pipe, and water age in certain parts of system); [4]For example, in a chloraminated system.

Figure 9. Lead Corrosion Control Strategy Decision Tree (Source: Brown et al. 2013)

5.2 Water Quality Impacts on Solubility and Scale Stability in Tacoma Water's System

The project team developed theoretical models to predict lead solubility for Tacoma Water's water. These models were used to compare Green River and groundwater qualities and predict how changes in pH and alkalinity would affect lead release in the system. The two major Pb(II) equilibrium solids according to solubility theory are cerussite [$Pb(II)CO_3(s)$] and hydrocerussite [$Pb(II)_3(CO_3)_2(OH)_2(s)$]. Hydrocerussite is predicted to be the controlling solid for GRFF water with a low DIC. Formation of hydrocerussite was observed on pipe sections exposed to GRFF water during pilot testing. Cerussite is predicted to be the controlling solid for high DIC groundwater, and was observed on pipe sections exposed to groundwater during the same testing. Cerussite is a less stable compound compared to hydrocerussite and is more prone to sloughing and formation of particulate lead.

As noted earlier in the Task 200 discussion, covering McMillin Reservoir in 2012 and implementing filtration of the Green River supply in December 2014 has caused pH stability to improve significantly. Additionally, systemwide chlorine residual levels (measured from TCR sites within the distribution system) have averaged approximately 0.8 mg/L, despite considerably lower chlorine dosages at the GRFF. This simultaneous improvement in chlorine residual stability and pH likely resulted in the lowest 90th percentile and median lead levels ever measured under Tacoma Water's LCR compliance program. It is quite possible that Pb(IV) scales, which are more stable and less dissolved than Pb(II) scales, were able to form at locations where chlorine was ≥ 0.8 mg/L and pH was ≥ 8.0 in low DIC GRFF water.

5.3 Groundwater Blending Analysis

When Tacoma Water brings on South Tacoma groundwater supplies, some degree of blending may occur through HSR prior to distribution. Four likely water quality blends were selected for further analysis:

- Scenario 1 - Current GRFF (pH/Alk 8.2/20) and moderate GW (pH/Alk 7.4/100)
- Scenario 2 - Current GRFF (pH/Alk 8.2/20) and increased GW (pH/Alk 7.8/105)
- Scenario 3 - Modified GRFF (pH/Alk 8.6/35) and moderate GW (pH/Alk 7.4/100)
- Scenario 4 - Modified GRFF (pH/Alk 8.6/35) and increased GW (pH/Alk 7.8/105)

The modeling indicated that raising the pH of the groundwater to 7.8 has an overall greater impact on blended pH than does raising the pH and alkalinity of the GRFF. This is not surprising given the significantly higher alkalinity of the groundwater supplies. However, also as expected, raising the pH and alkalinity of the GRFF does maintain a higher blended pH compared to current conditions until ≥ 70 percent groundwater is blended into the Green River water.

5.4 Conclusions and Recommended Set Points

The Task 400 task drew upon the Task 200 data, published corrosion literature, developed lead solubility models, the Task 300 pilot testing, and scale analysis results to evaluate impacts of GRFF and groundwater from the South Tacoma Wellfield (the principal groundwater source for Tacoma Water) on lead release and scale stability. The following is a summary of conclusions and observations.

5.4.1 Impact of pH

- The current pH/alkalinity conditions for the GRFF resulted in historically low 90th percentile lead results (2 µg/L), based on one round of compliance monitoring, when groundwater was not in use. These results indicate excellent lead control when Green River water is supplied.
- Further increasing pH in groundwater sources would result in some reduction in lead release for regions receiving primarily groundwater. However, reductions are expected to be marginal because of elevated DIC, and expensive to implement due to the high buffering capacity of the groundwater supplies. Lower pH targets are appropriate for the high DIC groundwater supplies compared to the low DIC surface water supply. Nonetheless, minimum pH targets should be maintained in the groundwater supplies to reduce impacts upon blending with GRFF water.
- pH has a stronger impact on lead solubility in low DIC surface water compared to high DIC groundwater. As such, more meaningful reductions in lead solubility (should they be needed in the future), as well as increased buffering against pH/DIC changes upon blending with groundwater, will be achievable by increasing the pH/alkalinity of the Green River treated water.

5.4.2 Impact of ORP

- Under ORP conditions, treated Green River water can likely form Pb(IV). Pb(IV) is less soluble and more stable than Pb(II) species.
- The rate of Pb(IV) formation is unknown and was not studied as part of this project.

- It is theoretically easier to form Pb(IV) in low DIC Green River water compared to high DIC groundwater. Nonetheless, increasing and maintaining higher ORP in groundwater supplies will reduce chlorine dilution impacts upon blending/changeover with GRFF water.
- Because chlorine residuals are expected to decline in premise plumbing during periods of stagnation, it is important to also maintain optimal pH/alkalinity/DIC conditions and avoid frequent switching between sources when operationally possible.
- Frequent changeovers from GRFF water to groundwater and vice versa likely impacts the ability to reach equilibrium and form stable lead scales. This is anticipated to increase primarily particulate lead. This consideration needs to be balanced with Tacoma Water's operational needs.
- As a side-benefit, increased chlorine should also help control release of iron from unlined cast iron pipes, especially in low-ORP groundwater supplies.
- Although it is assumed that disinfection byproduct (DBP) formation associated with treated Green River water is significantly lower now that filtration is on-line, DBP formation should be evaluated at all sources for which chlorine will be increased.

5.4.3 Preliminary Water Quality Set Points

Table 3 summarizes the preliminary entry point water quality set points that are recommended to serve as OCCT for Tacoma Water, based on the most recent round of LCR compliance monitoring, literature review, pilot testing, scale analysis, and solubility/blending modeling.

Table 3. Recommended Water Quality Set Points for Entry Points

Source of Supply/Entry point	Minimum* pH and alkalinity	Operational Set Points and Adjustment Method
Green River	pH 8.2, alkalinity 20mg/L as $CaCO_3$	pH 8.4 ± 0.2 using existing sodium hydroxide feed alkalinity 24 mg/L as $CaCO_3$ using existing sodium hydroxide and carbon dioxide feeds
Hood Street Reservoir	pH 7.4, no alkalinity set point	pH 7.6 ± 0.2 using existing sodium hydroxide feed
South Tacoma Pump Station	pH 7.4, no alkalinity set point	pH 7.4–7.6 using existing aeration system
Other Wells	pH 7.4, no alkalinity set point	pH 7.6 ± 0.2 using new sodium hydroxide feed or blending

*Noncompliance is based on the number of days the "daily average" (excursions) does not meet the designated WQP limit or range as calculated within a fixed 6-month period, per the LCR.

These minimum entry point set points were selected to provide control against lead release, recognizing that Tacoma is able to form Pb(IV) scales, and also to minimize the impact of blending of different waters in the distribution system. Due to the variable levels of blending and resultant DIC levels, it is not meaningful to set distribution optimal water quality parameters (other than using the lower groundwater pH). However, HDR recommends maintaining a chlorine residual of approximately 0.8 mg/L within the distribution system to maintain higher ORP conditions that favor the formation of less soluble Pb(IV) compounds. The higher ORP conditions the system can maintain, the more likely Pb(IV) is formed, especially in the low DIC GRFF supply.

These set points and recommendations are based on the theoretical modeling and the preliminary results of pilot testing, scale analysis, and full-scale data analysis and have been developed through consideration of the current LCR as well as its potential future revisions, which are expected to place an increased focus on minimizing lead release.

Furthermore, only one round of full-scale LCR monitoring has been conducted since GRFF became operational. If lower lead levels are required in the future, due to either changes in regulatory requirements or if new information is obtained during future LCR compliance monitoring rounds, this analysis shows that further increasing pH and alkalinity can lower lead solubility for the low DIC GRFF supply. Only minor additional reductions would be anticipated by increasing pH further for the high DIC groundwater supplies. Overall, we would recommend a phased approach along with other operational considerations as detailed in Table 4.

Table 4. Additional Considerations for Future Improvements

Source of Supply	Approach/future water quality targets
Green River	▪ Obtain next round of LCR compliance results under the recommended OCCT conditions. ▪ If additional lead reduction needed due to future regulatory requirements or LCR compliance monitoring, raise pH to 8.6 using sodium hydroxide. ▪ If inadequate buffering during blending with GW, and/or if lead requirements become more stringent, increase alkalinity to 35 mg/L as $CaCO_3$ (DIC=8.2mg/L). pH adjustment to a maximum of 9.0 may be needed in the future. However, no additional Alk/DIC adjustment beyond 35 would be recommended for GRFF supply. Goal is to maintain hydrocerussite (low DIC water) rather than form cerussite scales, in locations where Pb(IV) cannot be maintained.
Hood Street Reservoir	▪ No minimum alkalinity target is recommended. ▪ Maximize use of higher pH/lower alkalinity (lower DIC) wells where possible. ▪ Goal is to produce waters with more consistent DIC leaving the reservoir site. ▪ If needed, increase pH to 7.8 and keep the alkalinity at or below 100 mg/L. Consider need for increased chlorine residual.
South Tacoma Pump Station	▪ No minimum alkalinity target is recommended. ▪ Maximize use of higher pH/lower alkalinity (lower DIC) wells where possible. ▪ Goal is to continue avoiding frequent on/off cycles of these wells, and production of more consistent DIC water out of the pump station. ▪ If needed, increase pH to 7.8 and keep the alkalinity at or below 100 mg/L. Consider need for increased chlorine residual.
Other Wells	Same as HSR and STPS

6 Task 500 – Proposed Capital and Operational Improvements

Each of Tacoma Water's supplies and treatment facilities were examined to determine the capital and operational improvements necessary to meet the Task 400 set points presented in Table 3. Chemical doses were established and estimates of budgetary-level capital and annual operating costs for each facility were developed. The full evaluation of capital and operational improvements can be found in Appendix D.

6.1 Basis of Evaluation

Table 3 lists the minimum water quality set points. Tacoma Water operations typically maintain pH within a range of ±0.2. In order to meet the listed minimum pH set points, operating set points have also been established to ensure minimum pH set points are always maintained such that the low end of the operational set point is equal to the minimum set point.

The first analysis was to determine if operational changes can be made to avoid or minimize a capital improvement at the existing LCR-related treatment facilities: GRFF, the Hood Street Reservoir Corrosion Control and Fluoridation Facility, and the South Tacoma Pump Station. Each of these facilities has their challenges in making substantial challenges, including:

- Green River Filtration Facility
  - Increased sodium hydroxide and carbon dioxide dosages are expensive due to the quantity of chemical required to treat the large flowrate.
  - A higher pH at the GRFF increases the chlorine x time disinfection requirements for Giardia.
  - The location and capacity of the existing carbon dioxide system leads to a lack of flexibility and may not achieve higher alkalinities.
  - The diurnal pH swings in the raw Green River water can complicate establishing a narrow pH set point.
- Hood Street Reservoir Corrosion Control and Fluoridation Facility
  - The various wells treated by this facility have a wide range of pH and alkalinities, and thus have very different sodium hydroxide doses.
  - The physical configuration of the South Tacoma Wellfield pipeline results in varying hydraulic transients as wells are turned on and off.
  - The combination of varying chemistry and hydraulic transients makes hitting a set point more challenging than at the GRFF.
- South Tacoma Pump Station aeration system.
  - As with the HSR Corrosion Control and Fluoridation Facility, the different wells treated by this facility have a wide range of pH and alkalinities, which results in varying dissolved carbon dioxide concentrations.
  - The aeration system operates at a fixed speed so the treated water pH varies depending on the well supplying the pump station and the overall pump station flowrate.

All of other groundwater supplies required improvements because the existing sodium hydroxide system was deficient (SE2/SE6) or they lacked any corrosion treatment (all other wells). Estimates of chemical dosing were developed using the Rothberg, Tamburini, and Winsor (RTW) Model for Corrosion Control and Process Chemistry (AWWA 1996) and are shown in Table 5. While this is a useful tool for planning-level evaluation of chemical dosing and resultant impacts, chemical doses, and resultant feed and storage requirements, the model output needs to be verified through bench-scale jar testing prior to the final design of any capital improvements.

Table 5. Estimated Dosage and Capital Improvements for Duty Wells

Well Facility[1]	Well Capacity (MGD)	Operating pH	25% Sodium Hydroxide Dose (Average mg/L)[2]	Improvement
Prairie Ridge Springs	0.8	7.6	4 mg/L	Add paving for chemical delivery trucks. Demo existing building and replace with CMU building. Increase chlorine storage capacity and sodium hydroxide storage and feed system. Install secondary containment and eyewash station.
GPL1 and GPL2	8.0	7.6	13 mg/L	Addition of sodium hydroxide. Rerouting of GPL1 discharge piping to GPL2. Pave road up to GPL2 site. Install sewer connection for spill disposal.
SE11/SE11A	2.0	7.6	7 mg/L	Install single sodium hydroxide building between the two well houses. Widen and pave lane up to the new sodium hydroxide building and turnaround lane for truck deliveries. Replace existing 12-inch PVC pipe with ductile iron and combine SE11 and SE11A discharge piping.
SE8	0.7	7.6	13 mg/L	Install single sodium hydroxide building.
SE2/SE6	1.2	7.6	15 mg/L	Remove and replace sodium hydroxide storage tank and feed system. Remove and replace PVC piping with ductile iron piping. Upgrade chlorination system.
Portland Avenue	1.7	7.6	None – blending or aeration	Blend with Green River water entering the PAR. If blending is not operational feasible, construct a packed tower aeration system and regrade for better site access.
UP1	1.6	7.6	6 mg/L	Install sodium hydroxide storage and feed system.

Note:
1. Emergency wells were not analyzed.
2. Dose represents RTW-modeled average conditions. Based on the experience with the HSR Corrosion Control and Fluoridation Facility, doses calculated using the RTW model have under-estimated actual full-scale chemical dosages.

The water from the GRFF and HSR Corrosion Control and Fluoridation Facility is fluoridated whereas all other water supplies are not. Tacoma Water has decided that fluoridation is not required for these infrequently used supplies until usage significantly increases in the future. Fluoridation exerts a small impact on pH if sodium fluoride salt is used, and a large impact if hydrofluorosilicic acid is used. The calculated sodium hydroxide dosages will need to be reevaluated if Tacoma Water decides to implement fluoridation for all water supplies.

6.2 Basis of Cost Estimating

The developed capital cost estimates associated with each of the identified capital improvements are based on the following general factors:

- The average recorded pH has been used to develop an estimate of the average dosage and average storage volume required.
- Redundancy is provided for chemical pumps and storage for sodium hypochlorite, but not for sodium hydroxide or instrumentation.
- Unit costs for buildings, site work, and site piping is based on recent construction bid values for similar construction.
- Buildings will be slab-on-grade with concrete masonry unit (CMU) walls, metal roofs, interior lighting and outlets, ventilation, and unit heaters.
- Electrical and instrumentation and controls (I&C) work is set at 10 percent of the major construction subtotal.
- Contractor mobilization is set at 10 percent of the major construction subtotal.
- Contractor overhead and profit is set at 15 percent of the major construction subtotal.
- Sales tax of 10.1 percent.

These additional costs are considered a Class 4 (concept study) estimate per AACE International for which an allowance of 50 percent is added for undefined scopes of work.

At the date of this memorandum, the Engineering News-Record Construction Cost Index for Seattle is 11442.97 (Engineering News-Record does not report a construction cost index for Tacoma) and the RSMeans Cost Index for Tacoma is 102.4.

The developed estimates are for today's construction costs only. The costs omit project cost line items such as:

- Inflation to the midpoint of the future construction period
- Any costs associated with SCADA improvements
- Engineering
- Consultant and contractor bidding costs
- Construction management
- Permitting and regulatory review fees
- Insurance
- Internal Tacoma Water project oversight and administration costs

These costs must be considered by Tacoma Water for proper budgeting in a capital improvement program. The operational costs are based on the following assumptions:

- Identified chemical volumes are delivered to a generic address in Tacoma. Site-specific constraints and/or locations may change the delivered chemical cost.
- Labor is assumed to be absorbed into the current in-town mechanics labor budget given the historical and projected future infrequent use of these wells. No additional labor costs are incurred.

- Electricity and natural gas usage for lighting, SCADA and controls, heating, security systems are assumed to be very low and are not explicitly calculated for this conceptual evaluation. Pumping costs are also not included due to the historical and projected future infrequent use of these wells.
- No annualized renewal and replacement funding was identified.

These assumptions need to be reevaluated when a capital improvement is being designed.

6.3 Cost Summary

Table 6 presents the capital and chemical costs for each of Tacoma Water's facilities needed to meet the recommended water quality set points determined during this study.

Table 6. Recommended Corrosion Control Improvements and Associated Construction Cost Estimates

Facility	Major Capital Improvements	Estimated Construction Cost	Estimated Additional Daily Chemical Cost
Green River and North Fork Wellfield	No capital improvements are needed.	-	$400
South Tacoma Wellfield – HSR Corrosion Control and Fluoridation Facility	No capital improvements are needed.	-	
South Tacoma Wellfield – South Tacoma Pump Station	No capital improvements are needed.	-	
Prairie Ridge Springs	Replace existing chlorine building with larger building for sodium hydroxide and chlorine storage and feed.	$557,000	$41
Wells GPL1 and GPL2	Construct new building to supply sodium hydroxide to both wells.	$1,099,000	$474
Wells SE11/SE11A	Construct new building to supply sodium hydroxide to both wells and replace existing substandard piping.	$529,000	$109
Well SE8	Construct new building to supply sodium hydroxide to the well.	$169,000	$75
Wells SE2/SE6	Remove and replace existing sodium hydroxide storage tank and feed system, replace existing substandard piping, and upgrade existing chlorination system.	$384,000	$108
Portland Avenue Well	No capital improvements are needed at this if blending is implemented. Otherwise, construct a packed tower aeration system.	$1,038,000 if aeration is required	No chemicals required for blending or aeration
Well UP1	Construct new building to supply sodium hydroxide to the well.	$382,000	$84

Facility	Major Capital Improvements	Estimated Construction Cost	Estimated Additional Daily Chemical Cost

Notes:
1. All construction and daily chemical costs estimated in December 2017.
2. Estimated additional daily costs assume continuous operations at peak well supply.
3. Estimated additional chemical costs for the Green River and North Fork Wellfield include sodium hydroxide and CO_2.
4. Estimated additional daily chemical costs for all wells include sodium hydroxide and sodium hypochlorite.

7 Summary

Tacoma Water historically operated, and continues to operate, multiple water supplies to provide high levels of operational flexibility and supply resiliency. However, the untreated water quality of these supplies has been corrosive to premise plumbing and has resulted in lead release from premise plumbing in the utility service area. Tacoma Water has implemented multiple actions to reduce the lead release and stay in compliance with the LCR. One of the principal mechanisms for the release of the remaining trace lead concentrations detected in Tacoma Water's drinking water is from switching back and forth between the utility's Green River surface water supply and the various groundwater supplies, principally the South Tacoma Wellfield.

The purpose of this study is to determine the most appropriate means for reducing the lead release. The results determined that further reductions can be achieved by increasing the GRFF-treated water pH and alkalinity, increasing the pH for the groundwater that is not already adjusted upwards, and maintaining a high ORP throughout the distribution system with free chlorination.

Upon implementation of these adjustments, Tacoma Water should monitor the distribution system to determine:

- The reduction in lead concentrations from LCR compliance or investigative sampling,
- That distribution system pH with Green River water has increased because of the higher pH set point and establishing an alkalinity set point,
- That chlorine residuals are at >0.5 mg/L free chlorine throughout the distribution system to help maintain lead scales in the more stable Pb(IV) state,
- The difference in lead concentrations before and after implementing treatment in areas served by the infrequently used wells that previously did not have sodium hydroxide feed, and
- That DBP concentrations have not varied appreciably with higher chlorine residuals.