Housatonic
Water Works Company
Since 1897

SAVE THE DATE:

November 12, 2020

WHERE: Computer or Telephone

WHEN: November 12, 2020

TIME: 6:00 P.M.

Link Address:

https://us02web.zoom.us/j/82136448056?
pwd=VnFmWWVOaURHb21raE9ZUnlza08zQT09

Passcode: 992677

Telephone:

Dial in, voice-only : 929 205 6099

Webinar ID: 821 3644 8056

Passcode: 992677

HOUSATONIC WATER WORKS COMPANY
SINCE 1897

October 30, 2020

Dear Customers,

Housatonic Water Works Company has continuously served our community since 1897, and we pride ourselves on providing quality customer service. I want to assure you that we will make every effort to keep your best interests in mind.

In August we hired the Cornwell Engineering Group (Newport News, VA), a national leader in water treatment, to investigate the colored water events which occurred this past summer. Their comprehensive "desktop" study is now available on our website at housatonicwater.com and a brief summary of the study's conclusions is enclosed herein as well.

It appears that there are two separate causes of the colored water issues:

1. Suspended particles from hydraulic disturbances: Roily water observations originate during water main flushing, hydrant testing, and when water is used to battle fires. At these times there are high volumes of water moving through the distribution system. During these events sediment (iron rust) in the pipes gets stirred up. These disturbances often result in a turbid, darker colored water with suspended particles.

2. Clear yellow color from manganese: In both summer 2018 and summer 2020, some parts of the distribution system experienced a clear (transparent) water with a light yellow color. Based on Cornwell's recent data analysis, we now believe that yellow water was caused by manganese in the treated water. At all times, the low level of manganese was of no health risk.

Why did it take so long to identify the problem? It was imperative that the underlying causes of the problems were properly identified, and potential unintended consequences of alternative treatment solutions be analyzed thoroughly. It is our belief that sound science needs to lead the way in determining the path forward toward solutions.

We did not want emotions to affect the process and we had to resist some inappropriate and potentially harmful directives from the Commonwealth.

As we have gone through this process our understanding has changed, and so have the corresponding applicable solutions. We're letting science lead the way.

We hope you appreciate that our cautious and detailed approach to this issue demonstrates our sincere commitment towards improving the water quality issues and addressing your concerns.

We believe that we are now on the right path toward selecting and implementing an effective solution and potential manganese removal systems are being evaluated.

Would you like to learn more? **You are invited to attend our next Public Information meeting** via Zoom **at 6:00 pm on Thursday November 12, 2020**. The meeting will include a presentation by Cornwell Engineering and Dr. Richard Gullick of Water Compliance Solutions and a discussion of our new plans for permanently solving the problem.

They will explain our approach to identifying the cause of the colored water, and the action plan that is being discussed as a solution. ***Please join us for the meeting and ask any questions you may have!***

Sincerely yours,

James J Mercer

James J. Mercer

ZOOM Information:

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https://us02web.zoom.us/j/82136448056?pwd=VnFmWWVOaURHb21raE9ZUnlza08zQT09

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CORNWELL
ENGINEERING GROUP

October 29, 2020

Housatonic Water Works Company

Memorandum No. 15400-001

Subject: Summary of Desktop Study – Colored Water And Corrosion Assessment

Housatonic Water Works Company (HWWC) has tasked Cornwell Engineering Group, Inc. (Cornwell) with investigating colored water events occurring in their system, typically during the warmer months. This is a summary of a memorandum which includes analysis on HWWC water quality characteristics and their implications on solubility or precipitation of hardness, iron, manganese, lead, or copper.

Cornwell's findings based on current data indicate:

- Manganese concentrations above the secondary maximum contaminant limit (SMCL) of 0.05 mg/L are the identified source of the colored water. The manganese is in the treated water leaving the water treatment plant.
    - Manganese removal should be evaluated and implemented at the water treatment plant.
    - The use of polyphosphate or a blended phosphate product to sequester manganese is not recommended due to its potential to negatively impact lead and copper corrosion.
- Based on iron measurements during known colored water events and corrosivity indices (Larson-Skold Index), it does not appear that iron is the source of the colored water. However, technologies that remove manganese from source water will also remove iron prior to entering the distribution system.
- pH at point of entry (POE) should be maintained ≥7.4. This may be possible without pH adjustment. If future monitoring shows that these pH levels cannot be consistently achieved, pH adjustment should be evaluated.
- Free chlorine residual in the distribution system should be maintained above 0.2 mg/L in all parts of the distribution system in all seasons. Chlorine residuals below 0.2 mg/L are not effective at controlling microbial growth and could result in microbial induced corrosion.
- Continued monitoring of LCR homes and identification of lead sources in the customer homes is recommended. The observed copper measurements seem high given the conditions in the HWWC system.
- Collection of more POE data and sampling at customer homes during colored water events is recommended to identify other potential causes of colored water.
    - It is recommended that customers provide notifications of colored water events when they occur in order for HWWC to collect samples that accurately represent this water quality to correctly characterize the problem.

The conclusions and recommendations are summarized in the table below:

Summary of recommendations for treatment of metals

Metal	Problem	Evidence	Recommended solution
Lead	Maybe	AL exceedance in past compliance periods, though < AL for the 6 most recent periods after improving sampling procedures	Identify lead sources. If LCR data increase again over time then possibly re-evaluate CCT
Copper	Maybe	AL exceedance in past compliance periods. Theoretical modeling shows POE water likely is corrosive to copper, while the measured values are substantially higher than is typically observed.	Conduct laboratory solubility studies
Iron	No	Levels <SMCL	None needed, but manganese removal will likely remove iron (prior to POE)
Manganese	Yes	Levels >SMCL Colored water complaints	Evaluate removal via oxidation and filtration

CORNWELL
ENGINEERING GROUP

October 29, 2020
Housatonic Water Works
Memorandum No. 15400-002

Subject: **Desktop Study – Colored Water and Corrosion Assessment**

Housatonic Water Works Company (HWWC) has tasked Cornwell Engineering Group, Inc. (Cornwell) with investigating the colored water events that seasonally occur in their system (typically during warner months), as well as the corrosivity of the water. The following memorandum discusses and summarizes the HWWC water quality characteristics and their implications on solubility or precipitation of hardness, iron, manganese, lead, or copper, and provides direction for an action plan to resolve the issues.

SYSTEM DESCRIPTION

The water source for the HWWC system is surface water from Long Pond. Treatment consists of slow sand filtration, addition of sodium hypochlorite, and chlorine contact as depicted in the treatment schematic in Figure 1. Current average daily production is 0.11 MG.

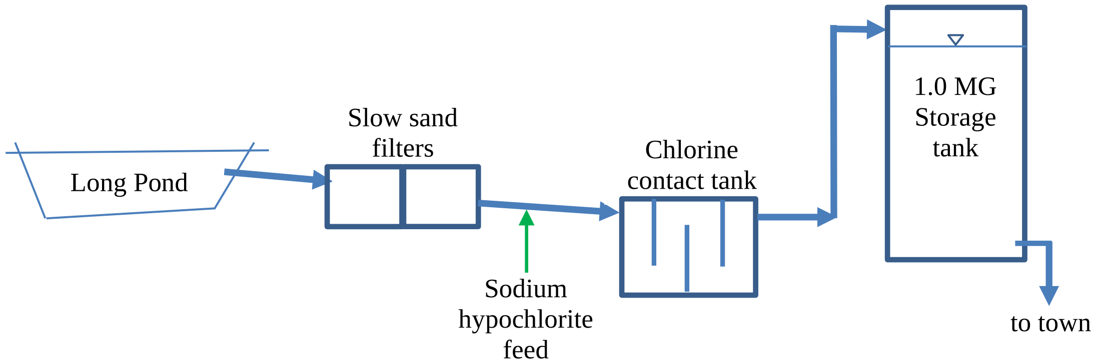

Figure 1 **HWWC treatment schematic**

Characteristics of the water mains and service lines, as reported in the December 2016 Desktop Study Report (Lenard 2016), are summarized in Table 1 and in the following items:

- Water main upgrades were initiated in the 1990s and included about 14,000 LF (mostly ductile iron and polyethylene as per Table 1), and most (if not all) of the remaining system pipes are >100 years old and are made of cast iron or steel.

- The characteristics of the “steel” pipe are not reported by Lenard (2016), but the data suggests that > 80 percent of the pipes are unlined cast iron or “steel” pipes >100 years old
- There are some asbestos cement (transite) pipes in the system. Information on sizes has not been reported, but these pipes are typically used for larger mains in a water system.
- No lead service lines have been identified in the system over the past ~35 years. Only a few lead goosenecks were encountered during that time, and they were removed. No other lead goosenecks are currently known to exist, and HWWC policy is to promptly remove any that may be found in the future.
- In addition to company-owned mains, there are approximately ten streets that are privately owned with privately owned water mains. These are typically steel lines, over 50 years old, and don’t have hydrants or blowoffs on the end to flush out stale or dirty water. This situation may impact water quality in these areas.

Table 1 HWWC Water Mains and Service Lines (Lenard 2016)

Water Mains		
Material	Lineal Feet (LF)	Percent of Total
Cast iron	64,497	54.3%
Steel†	34,734	29.2%
Ductile iron	14,671	12.3%
Transite (asbestos cement)	4,552	3.8%
Polyethylene (PE)	380	0.3%
Total	118,834	100.0%
Service Lines		
Material	Number	Percent of Total
Galvanized	784	91.6%
Copper	71	8.3%
Ductile Iron	1	0.1%
Total	856	100%

HWWC WATER QUALITY – ENTRY POINT AND DISTRIBUTION SYSTEM

Historical data are summarized in Table 2, with data from the distribution system separated by low color (<15 PCU) and high color (>15 PCU). Data for the distribution system includes data from August 22, 2018 through March 16, 2020 plus data from additional five sampling events in August 2020. Data for point of entry (POE) for pH from the WTP monitoring data was only used from July 27, 2020 through most recent data provided (September 7, 2020) due to pH probe calibration issues (Figure 5). Additional data at POE was also collected and measured by an independent laboratory, similar to the distribution sites. This additional POE data included 5 sampling events, one from August 22, 2018 and four from recent sampling events in August of 2020. Therefore, POE data may not be representative of conditions observed during the colder months. Calcium hardness at POE was reported in the 2016 desktop corrosion control treatment (CCT) study (Lenard 2016), and was assumed to be similar at the distribution sites for calculated values. Calculated parameters such as Larson and Skold Index (LSK), calcium carbonate precipitation potential (CCPP), dissolved inorganic carbon (DIC), and chloride to sulfate mass ratio (CSMR) are also included. Calculations for CCPP and DIC were performed assuming a water temperature of 20°C.

Since colored water is a main concern in the HWWC system, Table 2 separates distribution data by color above or below the secondary maximum contaminant level (SMCL) of 15 PCU. Note that colored water data are still limited.

Most of the other parameters and constituents are about the same at the POE and in the distribution system, and except for color and manganese the results during high color events (>15 PCU) are about the same as on low color events (<15 PCU). On dates when the color is >15 PCU, the manganese is higher than on the dates when the color is <15 PCU. More than half of the manganese results in the distribution system samples with color <15 PCU were below the detection limit (<0.002 mg/L): 86 of 155 samples, and 145 of the 155 samples were <0.010 mg/L. For distribution samples >15 PCU, no manganese values were below the detection limit. When the color was ≥30 PCU the manganese was ≥0.09 mg/L. Further discussion on manganese and colored water is included in the next section.

Iron, manganese, and total color data are evaluated in the discussion below, followed by a discussion of pH, lead and copper, use of polyphosphate, hardness precipitation, and free chlorine residuals.

Table 2 Housatonic Water Works Water Quality (2018 – 2020)

Parameter/Constituent	POE Median, n=5	DS (color>15 PCU) Median, n=6	DS (color<15 PCU) Median, n=155
pH*	7.3	7.7	7.8
Total Alkalinity (mg/L $CaCO_3$)	80	78	80
Calcium Hardness (mg/L $CaCO_3$)	48	--	--
Total Hardness (mg/L $CaCO_3$)	--	--	--
Total Iron (mg/L)	<0.05	0.093	<0.05
Total Manganese (mg/L)	0.086	0.018	<0.002
Chloride (mg/L)	14.2	14.3	14.7
Sulfate (mg/L)	<5	<5	<5
Free Chlorine Residual (mg/L)	1.13	0.45	0.35
Apparent color (PCU) †	20	20	0
Total Dissolved Solids (mg/L)	107	113	105
DIC (mg/L as C)*	21.9	19.8	19.9
LSK	<0.32	<0.52	<0.32
CCPP (mg/L $CaCO_3$)	-18.5		
Saturation pH	8.16		
LSI	-0.96		
CSMR (mg/mg)	>2.8	>2.8	>2.9

* = the POE pH data used to determine the median included five samples from an independent certified laboratory, plus one value per day from the treatment plant's analyzer from 7/27/20 through 9/27/20. The DIC was calculated using paired pH and alkalinity data on dates when alkalinity was also measured.
† = APHA platinum/cobalt (Pt/Co) color units, unfiltered[1] (ASTM 2019)
DIC = Dissolved inorganic carbon (also known as "total carbonate")
LSK = Larson-Skold Index
CCPP = Calcium carbonate precipitation potential ("+" = precipitation, "-" = dissolution)
LSI = Langelier Saturation Index
CSMR = Chloride to sulfate mass ratio

IRON AND MANGANESE

Results from Table 2 show that iron was consistently below the SMCL, even during high color events (>15 PCU). Previously colored water complaints were thought by HWWC to be from iron corrosion due to the aging iron pipes in the system, but none of the iron results reported, including samples with total color 40 to 50 PCU, exceeded the 0.3 mg/L iron SMCL.

The Larson-Skold Index (LSK) is used to describe the corrosivity of water towards iron, although it does not account for all iron corrosion mechanisms. Table 3 shows the interpretation with respect

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[1] "True" color (filtered water sample) is measured the same way as apparent color (unfiltered water sample), except with suspended material (e.g., turbidity) removed by filtration before determination of "true" color.

to potential for iron corrosion associated with calculated LSK values (Leitz and Guerra 2013). The index is calculated using the ratio of equivalent weight of chloride and sulfate ions to the equivalent weight of bicarbonate and carbonate ions, shown in the following equation.

$$\text{LSK}=\frac{(\text{Cl}^{-}+\text{SO}_4^{2-})}{(\text{HCO}_3^{-}+\text{CO}_3^{2-})}=\frac{\text{eq. weight of chloride}+\text{eq. weight of sulfate}}{\text{eq. weight of bicarbonate and carbonate}}$$

Table 3 Larson-Skold Index

(Source: Leitz and Guerra 2013)

LSK Value	Significance
< 0.8	Chloride and sulfate concentrations will not interfere with natural film formation
0.8 < LSK < 1.2	Chloride and sulfate concentrations may interfere with natural film formation; corrosion may occur
> 1.2	High corrosion rates are anticipated

Calculations based on the recent sampling, using POE alkalinity of 80 mg/L $CaCO_3$ as an estimate for the sum of carbonate and bicarbonate, a chloride of 14.2 mg/L, and sulfate as the detection limit of 5 mg/L, gives a Larson-Skold Index of about <0.32 (as shown in equation below)[2]. As shown in Table 3, an LSK of 0.3 suggests the water quality conditions are not conducive to iron corrosion. This is supported by the low measured iron levels in the distribution system, as levels are historically below the SMCL even during high color sampling events.

$$\text{LSK}=\frac{(\text{Cl}^{-}+\text{SO}_4^{2-})}{(\text{HCO}_3^{-}+\text{CO}_3^{2-})}\cong\frac{\left(\frac{14.2\ \text{mg/L}}{35.45\ \text{mg/meq}}\right)+\left(\frac{<5\ \text{mg/L}}{48\ \text{mg/meq}}\right)}{\left(\frac{80\ \text{mg/L as CaCO}_3}{50\ \text{mg/meq}}\right)}=<0.32$$

Figure 2 shows manganese in the raw water, at point of entry, and in the distribution system from Summer 2018 through Summer 2020. Manganese in the distribution system varies seasonally, with higher levels in the warmer months. Manganese exceeds the SMCL at the POE in multiple measurements in August 2018 and August 2020. One measurement in the distribution system in August 2018 is at the SMCL and two exceed the SMCL in August 2020. There are no data available for the colder months for manganese in the raw water and the point of entry.

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[2] The sum of the equivalent weights of carbonate and bicarbonate at normal pH of drinking water can be approximated as the alkalinity in mg/L as $CaCO_3$ divided by a factor of 50 mg $CaCO_3$ per meq

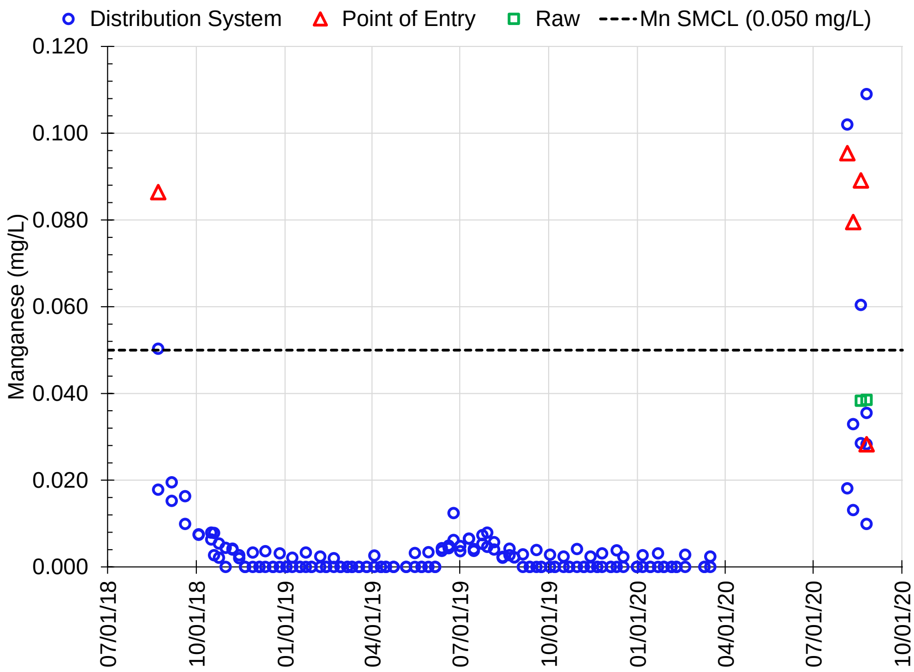

Figure 2 Manganese in raw, point of entry, and distribution system water

The higher manganese levels in the summer correspond to the same time period when most colored water complaints are received. Figure 3 compares manganese versus total color in samples where both were analyzed (see exception discussed later in this paragraph). This figure shows that events with manganese above the SMCL occur when there is high color in the same sample.

Figure 4 shows the same type of plot but with iron instead of manganese. This figure shows that even during high color events, the iron levels are below the SMCL of 0.3 mg/L. There does not appear to be any trend between high color events and high iron.

The results from these two figures for iron and manganese versus color show that:

a) iron never occurred above the SMCL, even during periods of total color up to 50 PCU

b) manganese increased on dates that higher total color was measured

c) for this particular limited data set of colored-water samples, manganese and color in the distribution system are similar to, or lower than, levels observed at the POE, suggesting that for these specific distribution system locations the color and manganese are not increasing to levels that are higher than at the entry point.

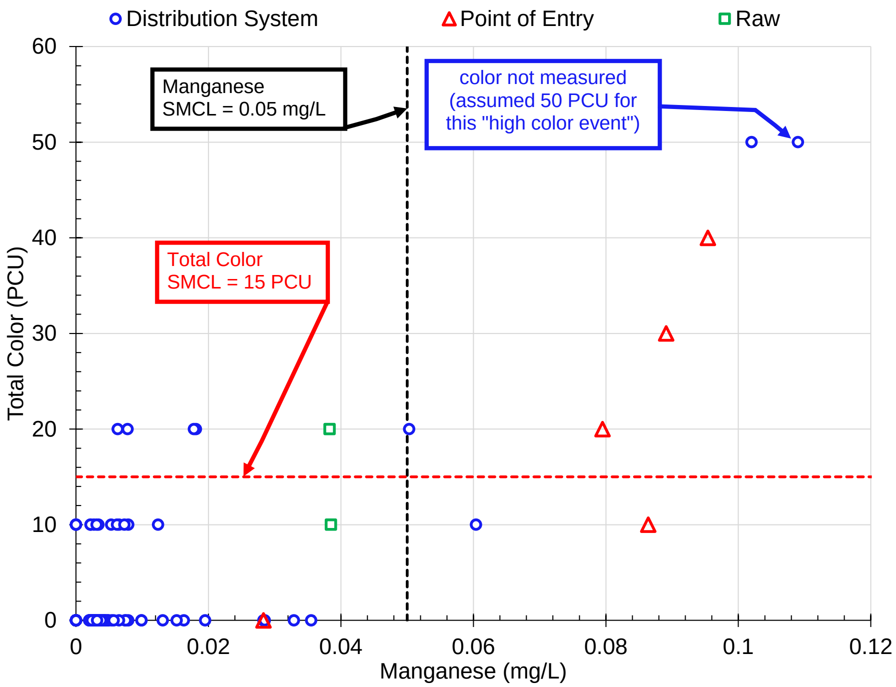

Figure 3 Manganese versus Total Color

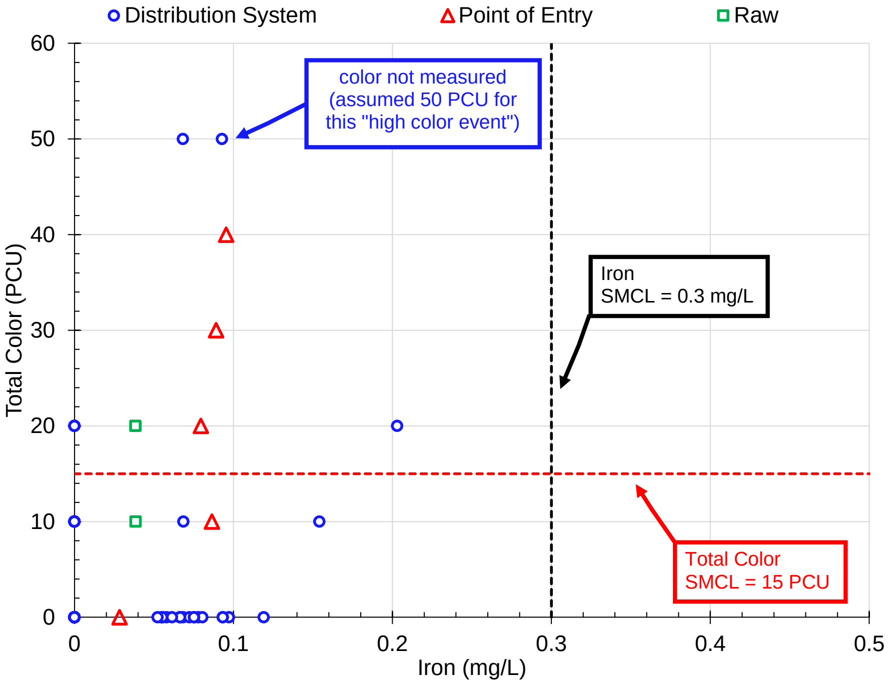

Figure 4 Iron versus Total Color

Following a hydraulic disturbance (e.g., main breaks or water main flushing) it is common for turbid water to be observed, and this has been reported in the HWWC system.

pH

HWWC provided water treatment plant data, which included pH data at two points in the water treatment process identified as “Segment 1” (exiting the contact tank) and “Segment 2” (point of entry). There were some reported issues with pH measurements at the WTP in the past, and the pH probes were re-calibrated on July 27, 2020. Figure 5 compares data before and after recalibration in the two segments, but only data after recalibration were used in Table 2 and in the following discussion. Dissolved inorganic carbon (DIC) is calculated from paired alkalinity and pH data, so only data after recalibration was used to calculate DIC at the POE. Distribution system monitoring locations have measured pH values ranging between approximately 7.2 to 8.2, though typically is in the range of 7.5 to 8.0 (Figure 6 and Figure 7). These figures demonstrate that there are fewer than 10 percent of pH values at any distribution system location that are <7.2..

The pH in the distribution system is within the desired range for lead and copper solubility control (see later discussion), so adjustment of pH at the WTP will not be necessary if this pH range can be maintained in the distribution system. Routine monitoring of the distribution system and WTP pH should be continued.

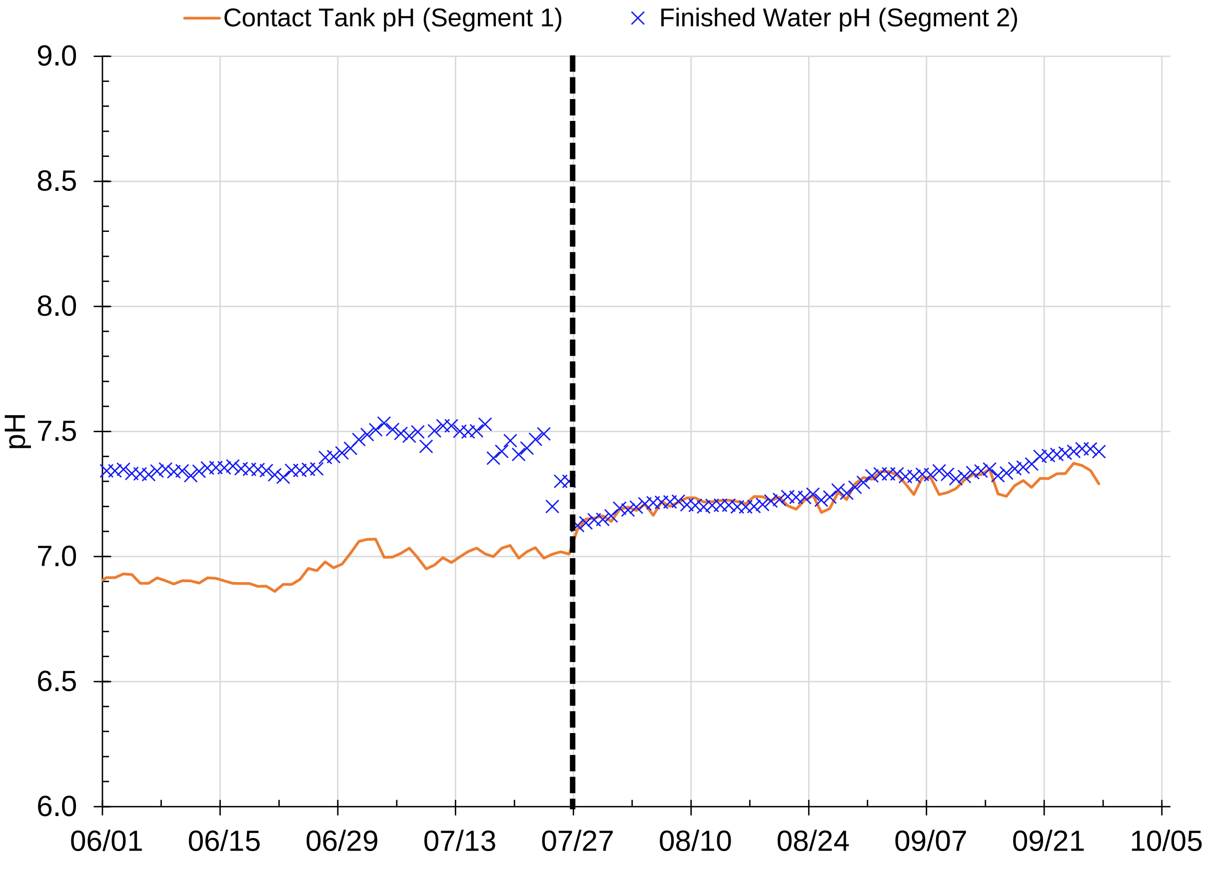

Figure 5 **Historical pH data for Segments 1 and 2 at the WTP (Through September 27, 2020)**

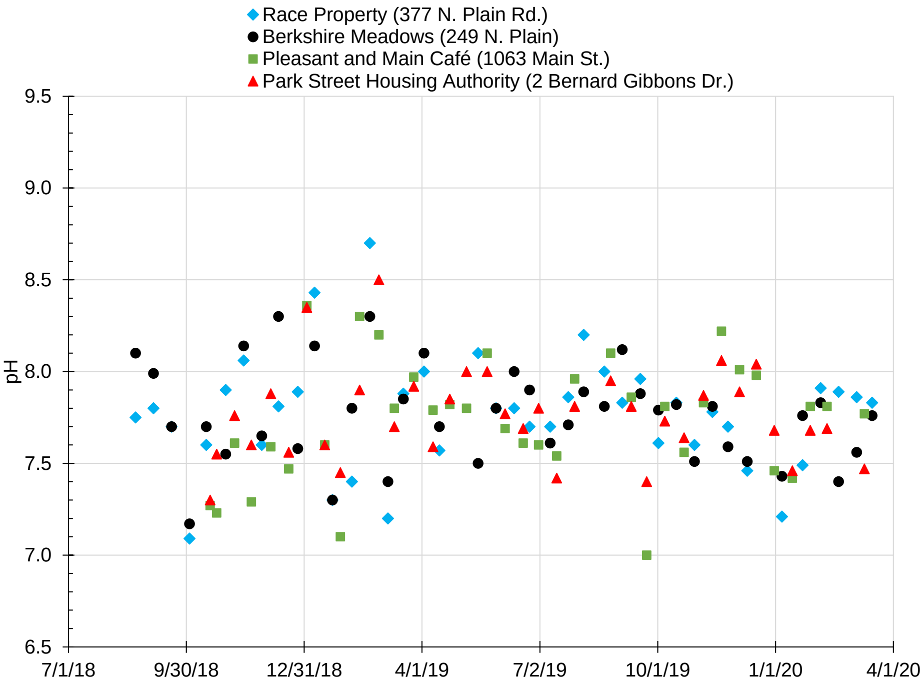

Figure 6 Distribution system (DS) pH versus date (August 2018 through August 2020)

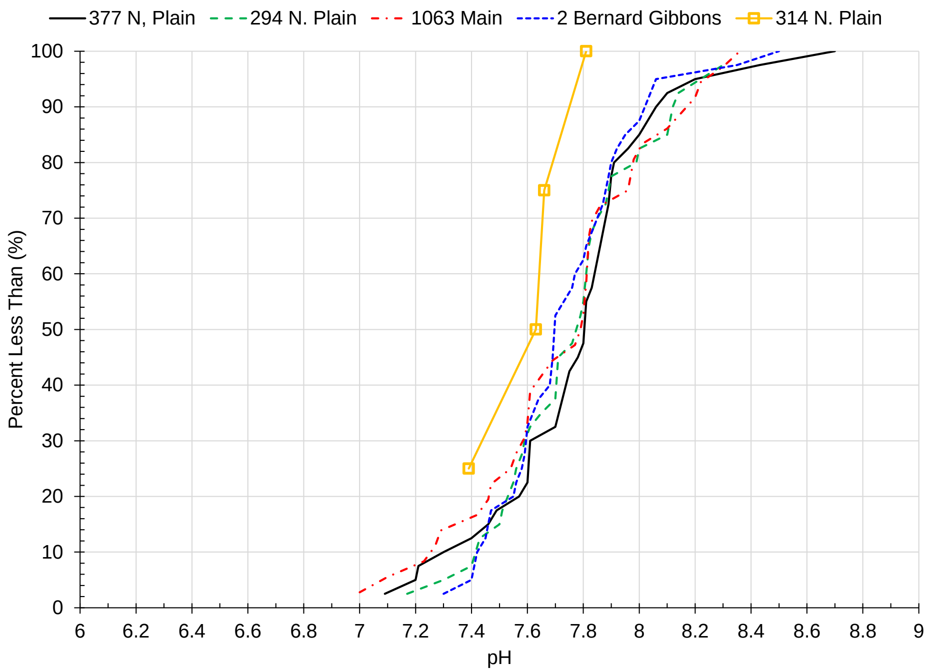

Figure 7 Percentile Distribution of DS pH (August 2018 through August 2020)

LEAD AND COPPER

Based on historical LCR data, lead and copper levels have been relatively high in certain compliance periods. In the last 7 years, there have been three lead action level (AL) exceedances and four copper action level exceedances. According to HWWC, some of the high lead levels in the system were due to a customer(s) not following LCR compliance sampling protocols. In response, HWWC implemented an education program for the sampling efforts. Recent data have been lower, without an Action Level exceedance in the past three years (six monitoring periods). Below is a summary table of the 90th percentile for lead and copper since 2013 (Table 4). Data from individual locations provided by HWWC also shows that high lead (or copper) results, including results leading to action level exceedances, are not limited to a single household location.

Table 4 Historical 90th percentile lead and copper data

Compliance Period	2013		2014	2015	2016		2017		2018		2019		2020
	Jun	Nov	Jun	Sep	Jun	Nov	Jun	Dec	Jun	Nov	May	Dec	Apr
Lead (µg/L)	16	6	6	15	18	19	17	14	7	5	12	6	3
Copper (mg/L)	1.4	1.0	1.1	1.4	1.4	1.1	1.0	0.2	1.6	1.3	1.0	0.9	0.8

Lead 90th percentile action level = 15 µg/L Copper 90th percentile action level = 1.3 mg/L

The lead and copper in recent years is trending lower. There has been no treatment change, other than maintenance of lower chlorine residuals (see later discussion about the need to maintain free chlorine residuals). Concentrations of lead and copper can be higher in warmer months, so monitoring results in warmer periods (June to September) should be noted to see if these trends continue. Even the 0.77 copper in April 2020 is high, based on Cornwell's experience, for an LCR compliance level since this is generally old copper at existing monitoring locations. For copper, a key issue is copper solubility after a new pipe or fixture is added. Old copper pipe can eventually develop a protective scale. However, new copper pipe has a higher solubility since it has not had time to form the protective scale. One way to evaluate the potential impact of adding new pipe is to use existing solubility models in the literature, as discussed below (note these models tend to overpredict solubility).

Theoretical and experimental solubility models for lead and copper were used to characterize HWWC water quality related to potential corrosion. A summary of recommended future actions for HWWC are included later in this memorandum. The lead and copper solubility relationships described in this memorandum are based on theoretical and experimentally determined conditions, and associated assumptions, that can be used for relative comparisons of different water sources. However, data evaluated by Cornwell in field and laboratory studies with water samples from various water systems has revealed that the relationships used to develop these curves result in conservative (high) estimates of lead and copper solubility. For example, we have found the results for copper solubility are from 3 to 6 times lower in actual treated water than are predicted from the Lytle equation discussed below. So, the HWWC water may not be corrosive to copper (or lead), though this can be verified in laboratory solubility studies.

Theoretical Copper Solubility

The DIC of the water entering the distribution system was estimated to be between 20 and 22 mg/L as C. This was calculated using paired alkalinity and pH data from Table 2.

The 90th percentile from LCR copper compliance data has been consistently ≥1.0 mg/L in the last 7 years, with 4 action level exceedances in the same time period. At HWWC there are some homes with copper service lines, and copper pipe and fittings are likely in premise plumbing.

Figure 8 depicts experimental copper solubility estimated using the equation below developed by Lytle et al (2018). The HWWC used in this figure is 21.9 mg/L as C, and curves are shown in the figure for four different pH values.

$$Cu = 56.68 \times e^{-0.77 \times pH} \times e^{-0.20 \times PO4} \times DIC^{0.59}$$

Where:
Cu = predicted copper solubility (mg/L)
pH = pH (unitless)
PO4 = orthophosphate residual in mg/L as PO4
DIC = dissolved inorganic carbon (mg/L as C)

The pH in homes in the distribution system typically range between 7.2 to 8.2. Results in this figure suggest that the control of copper corrosion is achievable without the addition of orthophosphate if the pH is consistently above 7.3, since copper solubility using the Lytle equation is 1.3 mg/L or less.

A range of water quality conditions deemed “corrosive” to copper are shown in Figure 9 (no orthophosphate present). This figure reflects definitions recommended during the NDWAC (National Drinking Water Advisory Committee) discussions for the new revisions to the LCR (NDWAC 2015a&b). Water quality that falls in the unshaded region is considered to be non-corrosive to copper. Conditions that plot in the shaded region are corrosive to copper unless orthophosphate (at proper dose and pH) is added. Paired pH and alkalinity data from distribution system monitoring locations are plotted in Figure 9. Figure 9 demonstrated that when the distribution pH is >7.2, the water quality conditions are not conducive to copper corrosion. Limited copper solubility would be expected in HWWC treated water without orthophosphate if the pH is maintained >7.2 under current alkalinity/DIC conditions, as shown in Figure 8 and Figure 9. Since HWWC copper levels are higher than expected based on theory and are higher than observed in most other surface water systems, additional evaluation of copper solubility for HWWC is recommended.

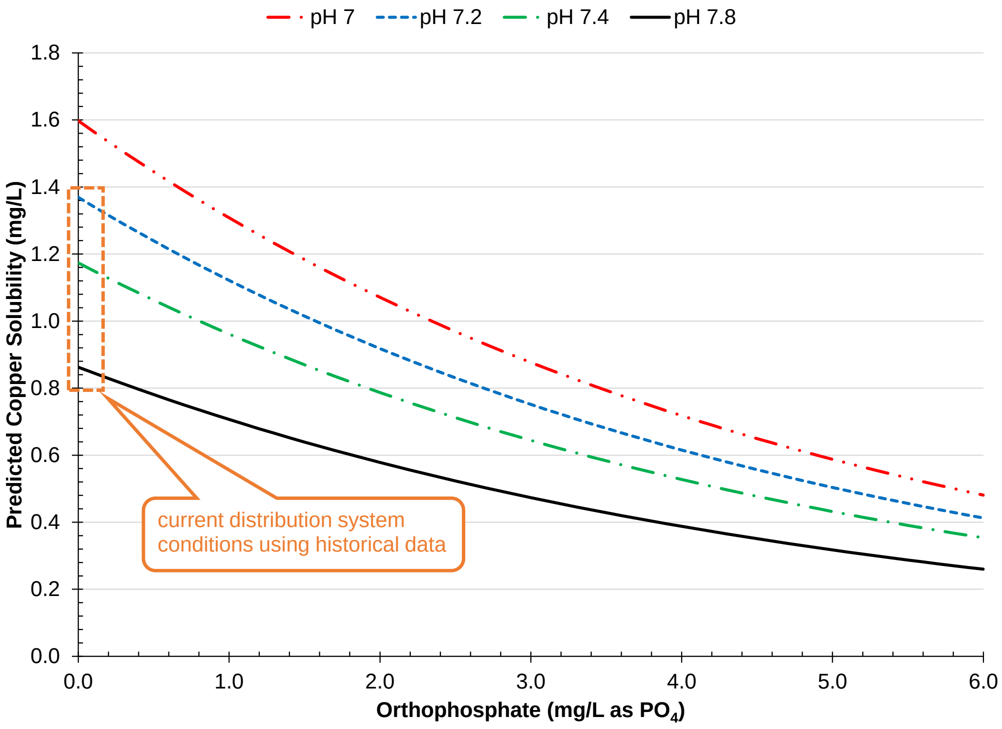

Figure 8 **Experimental copper solubility equation as a function of DIC, PO4, and pH. Assumes a constant DIC of 21.9 mg/L as C.**

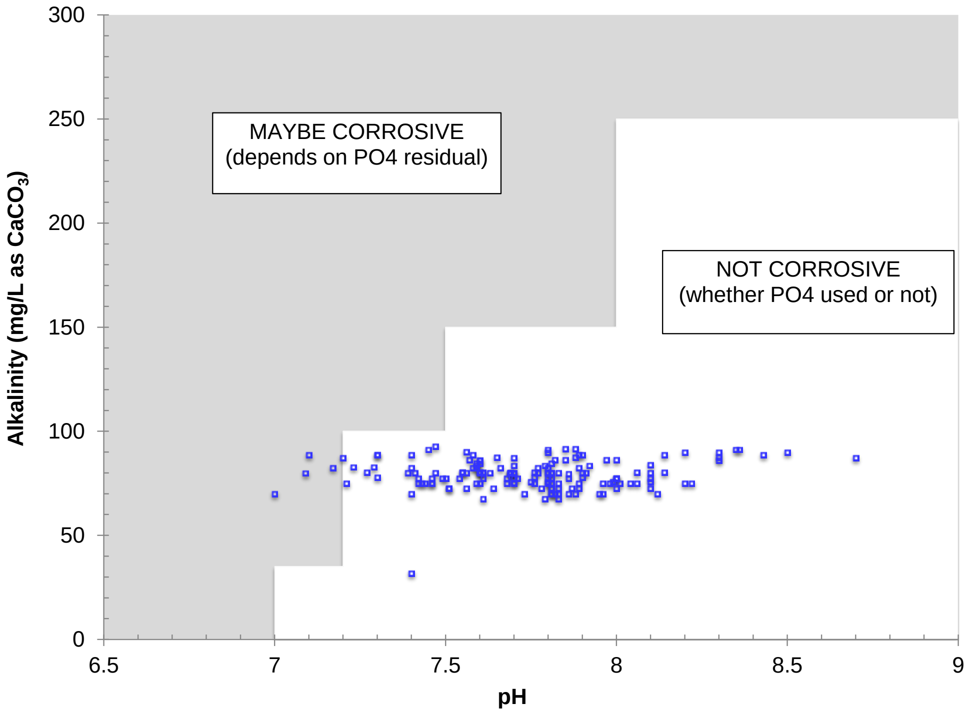

Figure 9 **NDWAC defined conditions corrosive to copper (no orthophosphate present) versus paired pH and alkalinity data from the distribution system**

Theoretical Lead Solubility

The HWWC system 90th percentile lead exceeded the 15 µg/L action level during 2016 and 2017, and has exceeded 10 µg/L at various times since 2013 (Table 4). Recent data have been more favorable (HWWC passed the lead AL for the past three years covering the most recent six monitoring periods, perhaps due to increased attention to proper sampling procedures). HWWC has indicated there are no known lead service lines or lead goosenecks in their system, and whenever they encountered lead goosenecks (just a few were found in 35 years), the goosenecks were removed. According to HWWC, >90 percent of the service lines are galvanized iron. LCR monitoring results indicate there are likely still some sources of lead somewhere, which may be within individual household plumbing, though it is unknown whether this is due to lead solder or brass plumbing fixtures, or some other lead-containing sources.

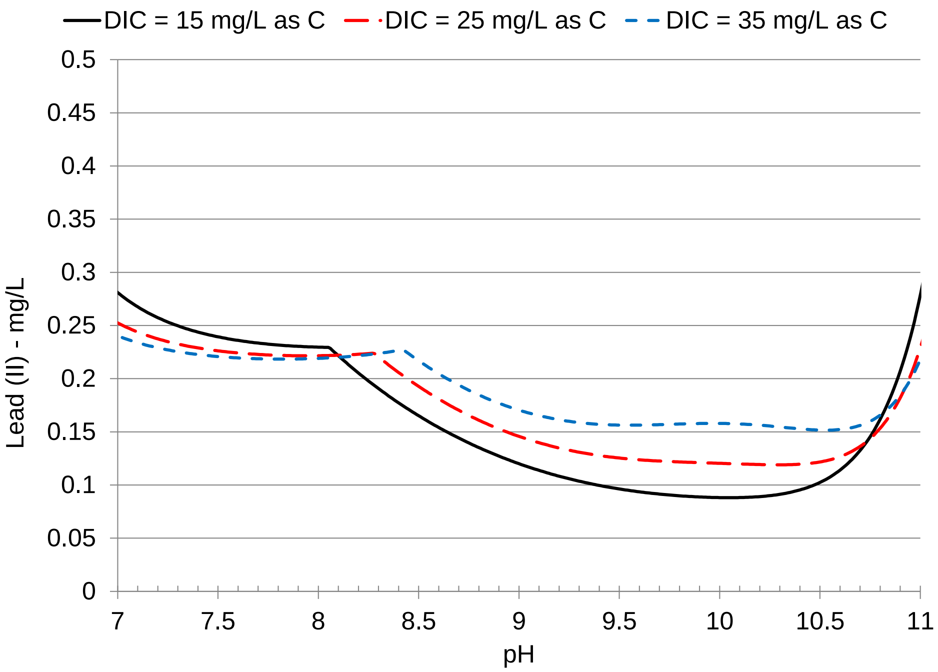

Figure 10 **Theoretical Lead Solubility from Visual MINTEQ**

Note: Assumes: a) DIC values are constant, b) water temperature 25 C, c) no orthophosphate present, d) no lead (IV) present, and e) cerussite and hydrocerussite are present**.**

Figure 10 is a theoretical lead solubility curve developed using chemical equilibrium mathematical model software (Visual MINTEQ (version 3.1 (https://vminteq.lwr.kth.se/)), literature data for stability constants and solubility products, water quality data (DIC, water temperature, pH), and assumed equilibrium with carbonate solids (hydrocerussite and cerussite). The curve was developed for three different DIC values of 15, 25, and 35 mg/L as C. The DIC of the HWWC system is similar to the 25 mg/L as C line in this figure. The figure indicates the pH would need to be raised to >9 in order to minimize the lead solubility without the use of orthophosphate. That is not recommended given the potential to precipitate calcium carbonate above the 8.2 saturation pH for this water source.

Figure 11 is a theoretical curve from Schock (2015) comparing lead solubility (vertical axis) with orthophosphate dose (horizontal axis). There are four sets of solid colored lines at bottom of the chart depicting predicted lead solubility at DIC 4.8 mg/L as C for pH 7.0, 7.5, 8.0, and 8.5. Similarly, higher in the graph are four lines for DIC 48.0 mg/L as C at the same four pH values. Note this graph assumes no polyphosphate present and assumes room temperature. This graph shows that:

- For a given DIC, when no orthophosphate is added, the lower the pH the higher the lead solubility.
- As PO_4 increases, lead solubility decreases for each combination of pH and DIC conditions.

For the HWWC system (DIC ~22 mg/L as C) the results would plot between the 4.8 and 48 mg/L DIC curves, and suggest the ability of orthophosphate to reduce the solubility of lead for the pH range of the HWWC system.

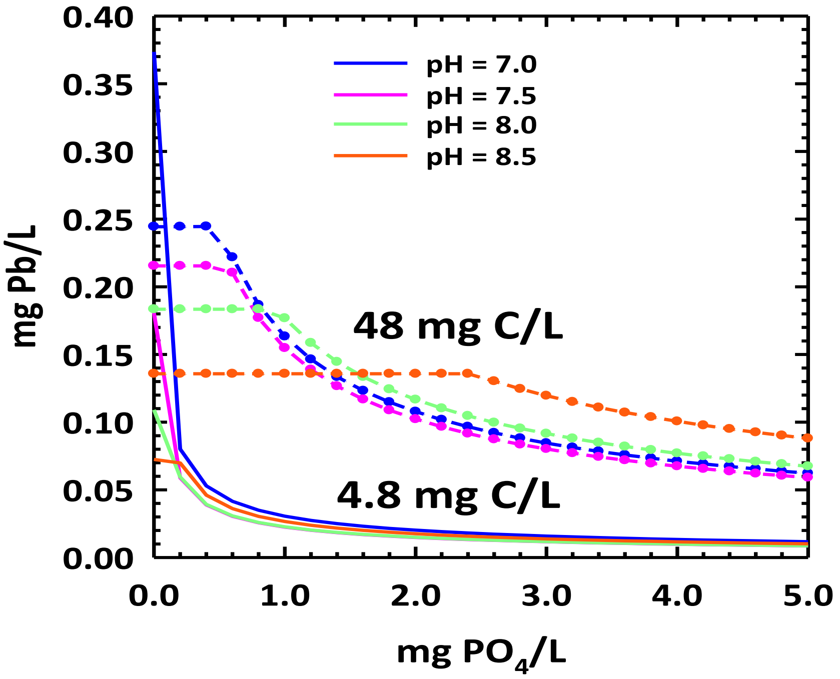

Figure 11 Lead solubility versus orthophosphate at 4.8 and 48 mg/L DIC at pH from 7.0 to 8.5 (Schock 2015)

USE OF POLYPHOSPHATE

Note that when this report refers to orthophosphate for lead and copper solubility control it is referring to the free PO_4 not a polyphosphate. Polyphosphate can be used to help keep iron and manganese from causing colored water and staining household plumbing and clothes. However, the use of polyphosphate complicates lead and copper corrosion control treatment.

Orthophosphate is used to promote formation of insoluble lead and copper phosphates. Polyphosphate added to keep iron and manganese from precipitating (i.e., forming scale), can also keep lead and copper from forming a protective crystalline scale. Furthermore, when lead and copper scales do form in the presence of polyphosphate, any polyphosphate incorporated into the scale can make the scale less stable. When polyphosphate is used with orthophosphate, the lead and copper solubility can be higher than if you add orthophosphate alone, although there is some amelioration of this as the polyphosphate gets older and naturally degrades from poly- to orthophosphate. Overall, there may be some instances where adding polyphosphate may be beneficial, especially when objectives other than lead and copper control are considered, but in most cases lead and copper control is optimized when orthophosphate is added alone.

Cornwell recommends adding iron or manganese removal when iron or manganese are above their SMCLs. Adding polyphosphate after this treatment will not be necessary for sequestration control of iron or manganese. In addition, if orthophosphate is needed for lead or copper control, it is recommended that it be added alone and not part of a blended phosphate. Since the treated water at the entry point in this system exceeds the 0.05 mg/L MCL for manganese, at least during warmer times of the year, it is recommended that treatment for manganese removal be added full-time, or at least seasonal, to limit manganese entering the distribution system. The best place to install manganese removal (and associated oxidation), orthophosphate injection, and any pH adjustment needs to be evaluated separately, though it is likely this will all happen following slow sand filtration.

HARDNESS AND CALCIUM CARBONATE PRECIPITATION

Since corrosion control methods may include pH adjustment, the calcium carbonate precipitation potential and saturation pH should be considered in order to anticipate the impact of raising or lowering the pH in a water system. The distribution pH ranges from about 7.2 to 8.2, and typically is between 7.5 and 8.0, which is below the saturation pH and the resulting CCPP is negative. Calcium carbonate precipitation is not expected in this water source unless the pH is raised above the saturation pH of 8.2. Distribution system pH should continue to be monitored to see if it consistently remains within the 7.2 to 8.2 range, and if additional lead or copper control is needed then it may be necessary to add orthophosphate (after evaluating dose and pH conditions needed). The current distribution system pH already ranges from 7.2 to 8.2 so an additional pH increase is not recommended due to potential calcium carbonate precipitation complications. The calcium hardness of the system is 48 mg/L as $CaCO_3$, but no total hardness data have been reported.

CHLORINE RESIDUAL

On occasion, distribution system chlorine residuals in late 2019 and early 2020 dipped below the minimum recommended target residual of 0.2 mg/L, as shown in Figure 12. The chlorine residual should be maintained at a higher level in the distribution system to ensure proper disinfection. These residuals need to balance other concerns (DBP formation versus microbial control – see also Roth and Cornwell 2018).

Corrosion chemistry is complex, and it is difficult to determine whether lower chlorine residual may or may not have any positive implication for lead or copper corrosion. Higher free chlorine can increase iron levels in the water, but it is also important to note that chlorine residuals that are too low can lead to microbial growth in the distribution system, which can result in lower pH and consequently can increase the solubility of lead, copper, iron, and other metals. Adjustment of free chlorine doses as necessary in order to achieve ≥0.2 mg/L residual in all parts of the distribution system in all seasons is recommended. This may require higher residuals in other parts of the system to ensure that all points in the system are ≥0.2 mg/L.

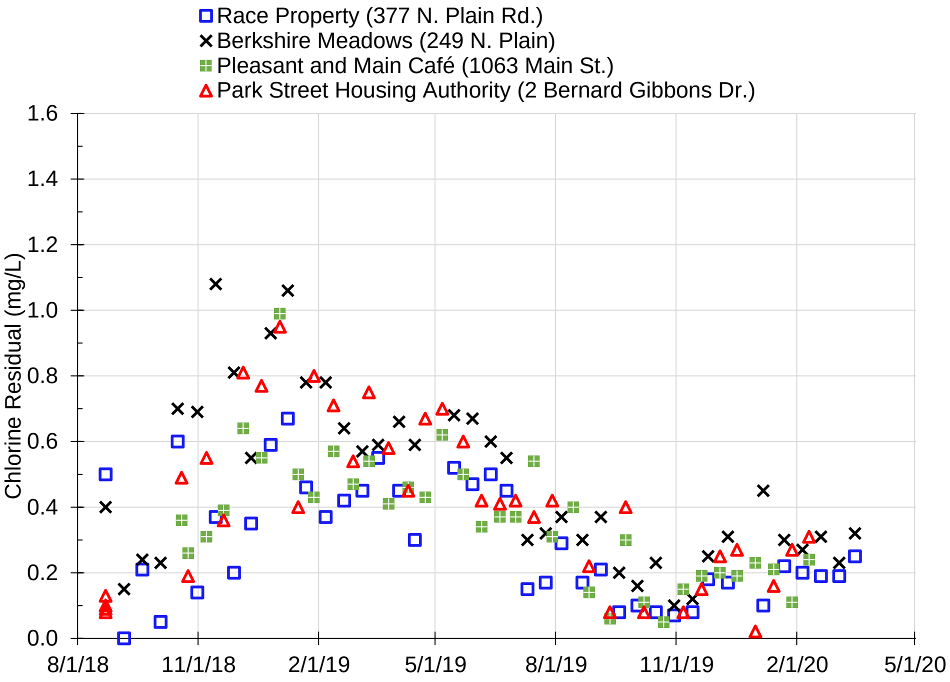

Figure 12 Distribution system chlorine residual

RECOMMENDATIONS AND ACTION PLAN

Based on previous analysis and discussion:

1. **Manganese concentrations above the secondary maximum contaminant limit (SMCL) of 0.05 mg/L are the identified source of the colored water. The manganese is in the treated water leaving the water treatment plant.**

2. Manganese removal should be evaluated and implemented at least seasonally (warmer weather) when higher manganese and higher true color results are observed.

3. The addition of a polyphosphate or a blended phosphate to sequester manganese or iron is not recommended. Polyphosphate or blended phosphate can have a negative effect on lead and copper corrosion.

4. Iron removal at the source does not appear to be necessary, but treatment installed for manganese removal should remove iron if present

5. The current water chemistry in the distribution system, using samples representing “normal” conditions, results in a low Larson-Skold Index, suggesting the water may not be susceptible to iron corrosion. Results from a designated “color event” also show an iron concentration well below the SMCL.

6. Based on the data reviewed, treated water pH has typically been ≥7.4 in the distribution system without pH adjustment. However, if future monitoring shows that these pH levels are not regularly achieved, pH adjustment should be evaluated.

7. Free chlorine residuals should be maintained at the target residual of ≥0.2 mg/L in all parts of the distribution system in all seasons.

8. Sequential sampling to identify locations of the lead source in the customers’ home or service lines is suggested for locations with historically high lead levels, and should also be considered after a treatment change, for example, after addition of: a) manganese removal processes, b) pH adjustment, or c) orthophosphate addition.

9. The current distribution system pH is already close to the saturation pH (8.2), so it may not be possible to increase the pH much higher. Consequently, if lead and copper cannot be controlled under current conditions, the addition of orthophosphate may need to be evaluated. Evaluation of orthophosphate and pH adjustment should include, at minimum,

laboratory solubility studies for lead and copper to evaluate optimal pH and orthophosphate dose.

The conclusions and recommendations for action are summarized in the table below:

Table 5 Summary of recommendations for treatment of metals

Metal	**Problem**	**Evidence**	**Recommended solution**
Lead	Maybe	Action Level (AL) exceedance in past compliance periods, though < AL for the 6 most recent periods after improving sampling procedures	Identify lead sources. If LCR data increase again over time then possibly re-evaluate CCT
Copper	Maybe	AL exceedance in past compliance periods. Theoretical modeling shows POE water likely is corrosive to copper, while the measured values are substantially higher than is typically observed.	Conduct laboratory solubility studies
Iron	No	Levels <SMCL	None needed, but manganese removal will likely remove iron (prior to POE)
Manganese	Yes	Levels >SMCL Colored water complaints	Evaluate removal via oxidation and filtration

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