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DRINKING WATER QUALITY INVESTIGATION

For Village of Weston Water Utility

Drinking Water Quality Investigation

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Report Versions

Date	Version	Comments
1/9/2018	Draft	For Village of Weston Water Utility review
1/23/2018	V 1.0	Finalized report
5/21/2018	V 1.1	Corrected dates – 2018 instead of 2017

Drinking Water Quality Investigation

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About Process Research Solutions, LLC

Process Research Solutions, LLC, is an engineering consulting firm specializing in water quality investigations for drinking water in municipal water systems and in building plumbing.

The company has also developed tools and protocols to pro-actively monitor and control water quality, lowering the chances of developing serious and expensive issues in water systems.

Data management computer software, My Monitoring Data®, has been developed by Process Research Solutions so that water quality and water system data can be quickly interpreted and utilized.

Section 1: Project Description

The Village of Weston water system has experienced elevated iron and manganese issues since it was established in 1968. Other water quality issues are interrelated with the iron and manganese issues.

Process Research Solutions, LLC was retained to define the possible mechanisms at work in the distribution system that shape the water quality and to suggest remedies to:

- Customer complaints of discolored water, most likely from elevated iron and manganese.
- Quick degradation of building hot water tanks, especially the increased corrosion of the tank's sacrificial anode.
- Buildup of soft material, for example, reddish brown material in the toilet tanks and in sinks around drains, in some buildings.
- Chlorine tastes and odors.
- Corrosion of Foremost Dairies heat exchangers possibly by elevated chlorides
- Degradation of asbestos-cement water mains that was found to release asbestos into water in 1982. (There is no longer an exceedance of asbestos fibers in the water, but any changes to water quality must take the integrity of the cement pipes into account. In addition, there is cement-lined ductile iron piping in the distribution system.)
- The presence of microbiological activity in the wells and in the distribution system as described by a 1995 engineering report.

It is also desired to assess systems operations in relation to the specific water quality issues listed above:

- Water treatment chemical addition
    - The dosing of chlorine for disinfection
    - The adjustment of pH of the treated water
    - The use of polyphosphate dosing for iron and manganese sequestration
- Water treatment processes
    - The use of air stripping for volatile organic compounds
    - Proposed iron and manganese removal
- System maintenance protocols
    - Well maintenance and cleaning
    - Distribution system flushing technique
- On-going monitoring for system water quality control
- Responding to water quality complaints

This report studies existing information on these topics and recommends an action plan to remedy issues and to improve systems operations under a cohesive strategy of improved consumer water quality.

Section 2: Project Approach: Comprehensive Perspective on Corrosion Control and Distribution System Water Quality Issues

Using data and observations from water quality investigations since 1992, Process Research Solutions has developed a comprehensive perspective of water quality and a method to utilize this perspective to lower the potential for distribution system water quality issues to occur. This includes lowering elevated lead and copper concentrations in the drinking water.

To understand this perspective and related methods, two documents are available:

- Water Research Foundation Project 4586 – download for free from waterrf.org
- CRC Press book on Monitoring (2nd edition) – purchase from crcpress.com

These concepts are best understood by comparing the comprehensive perspective of water quality with the mainstream regulatory perspective. Figure 2.1 begins the explanation of the comprehensive perspective by showing that drinking water flows through pipes with various quantities of chemical scales and biofilms that have built up on pipe walls over time.

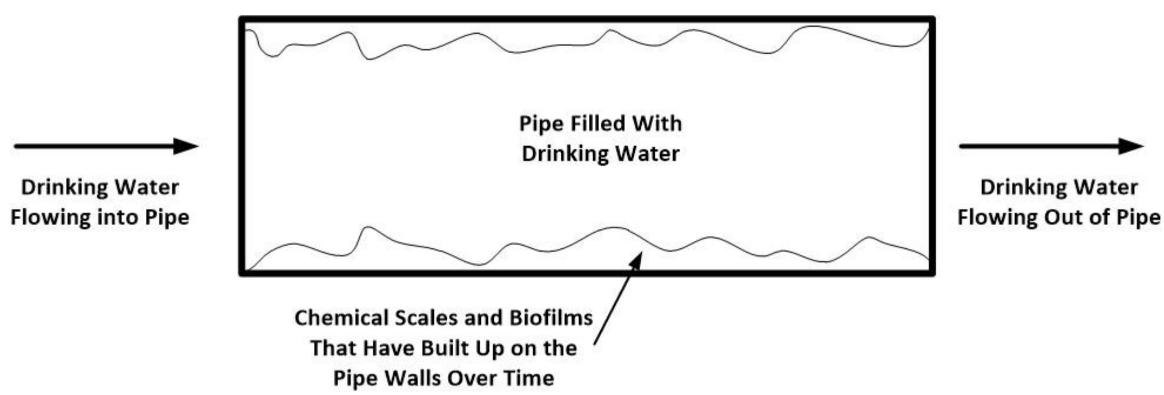

Figure 2.1 Typical Drinking Water Pipe

Figure 2.2 shows that the composition of the drinking water flowing into the pipe is quite complex – a mix of many different chemical compounds, nutrients for microorganisms, and a variety of naturally-occurring microorganisms.

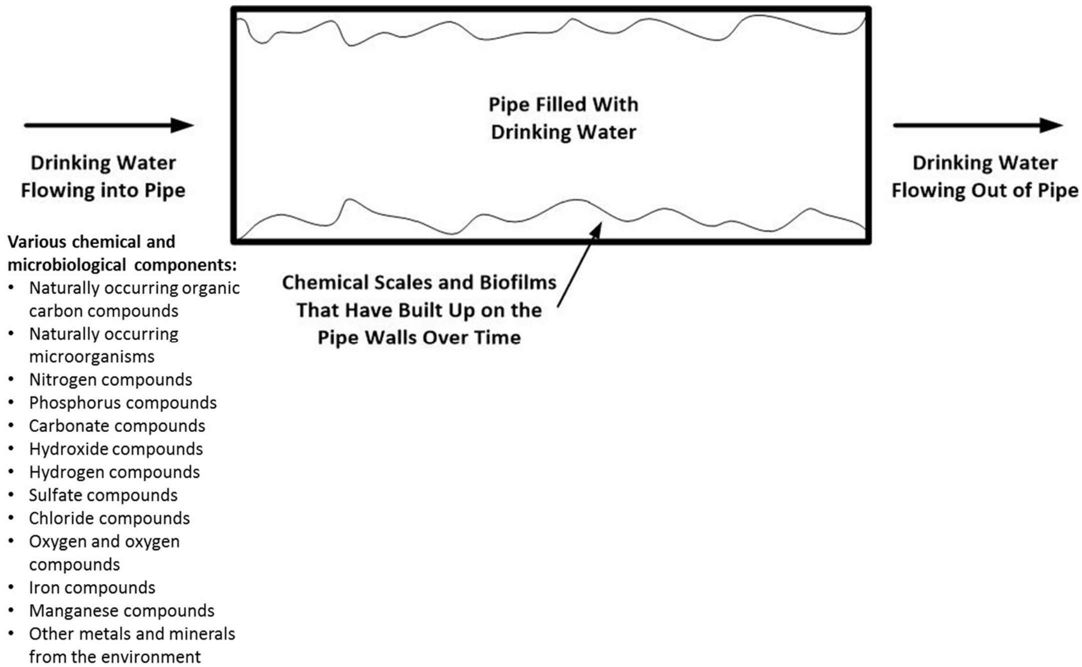

Figure 2.2 Typical Composition of Drinking Water Flowing into a Pipe

Typical interactions between the pipe walls and the drinking water are shown in Figure 2.3.

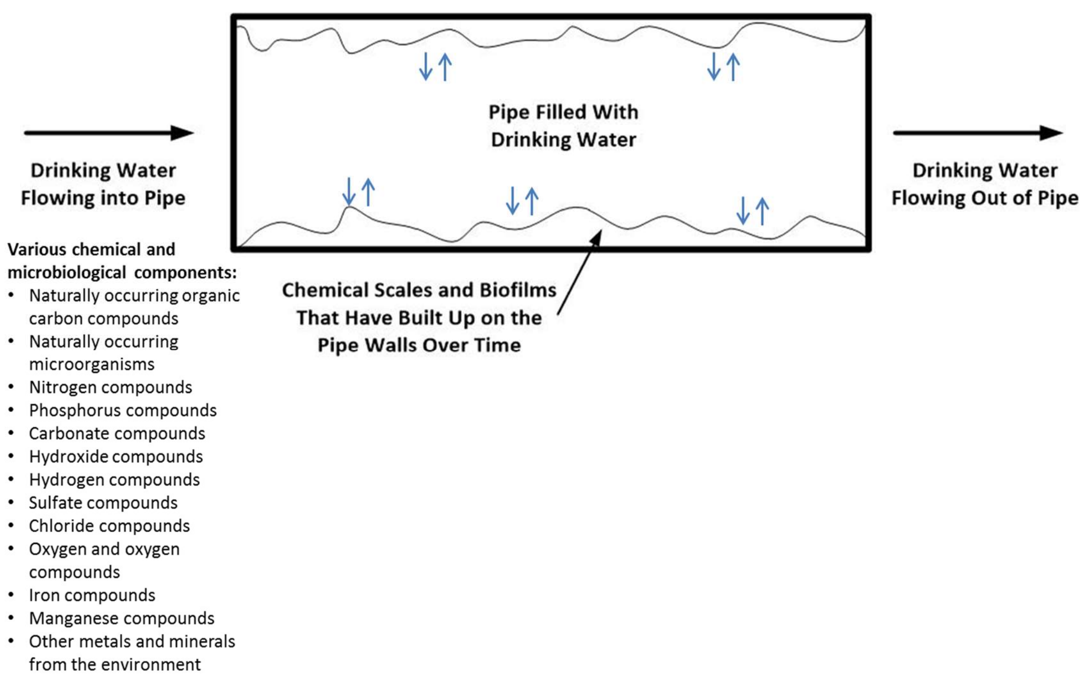

Figure 2.3 Typical Interactions between Pipe Walls and Drinking Water

A closer look at these typical interactions can be seen in Figure 2.4. Here, it is seen that interactions between water chemistry and microbiology entrained in the water and on pipe walls are quite complex. It is the resultant chemicals and microorganisms entrained and dissolved in the water that shape the water quality consumed.

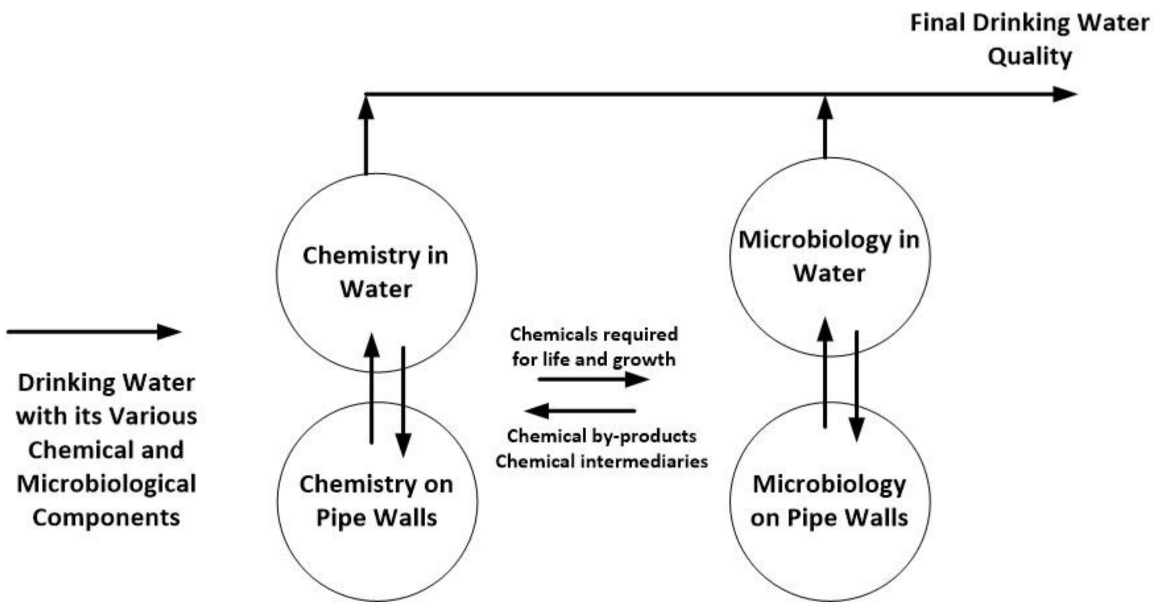

Figure 2.4 The Shaping of Water Quality

The resultant water quality can have a number of problems as listed in Figure 2.5. All of these problems are interrelated – manifestations of the same complex interactions between drinking water and pipe wall chemicals and biofilms.

Instead of using the comprehensive perspective of water quality, the drinking water regulations have a more simplified approach. Each distribution system drinking water quality problem is viewed separately. For example, for lead and copper corrosion, the regulations view drinking water as shown in Figure 2.6. Here, the water system is idealized into having only a simple scale of carbonates on the pipe wall with only carbonate compounds flowing into the pipe in the water.

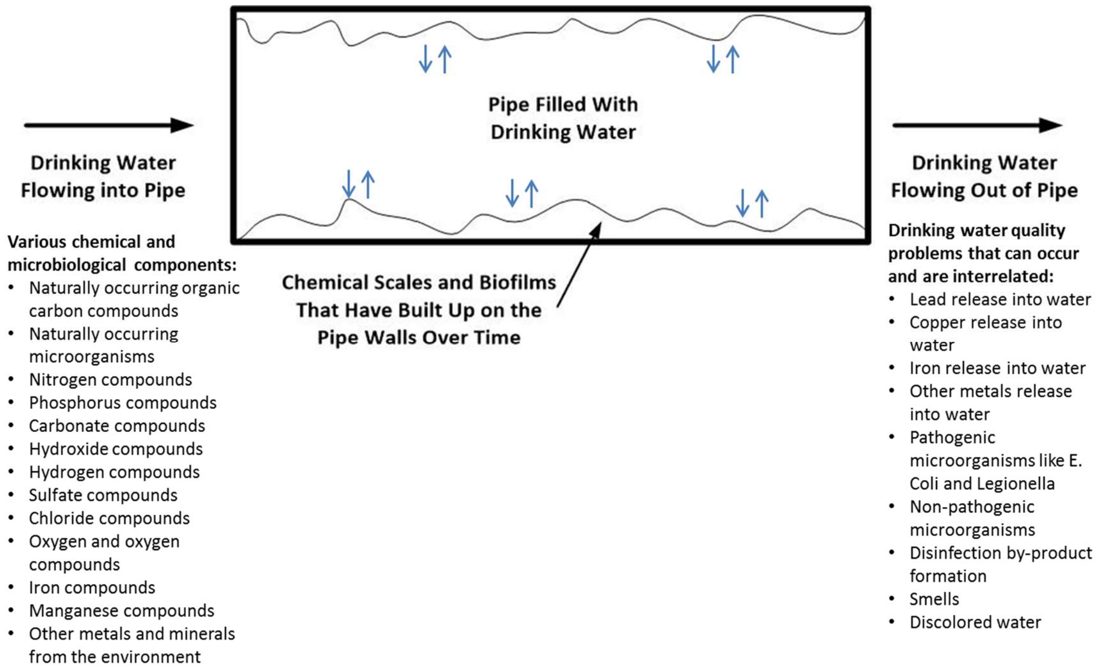

Figure 2.5 Interrelated Distribution System Drinking Water Quality Problems

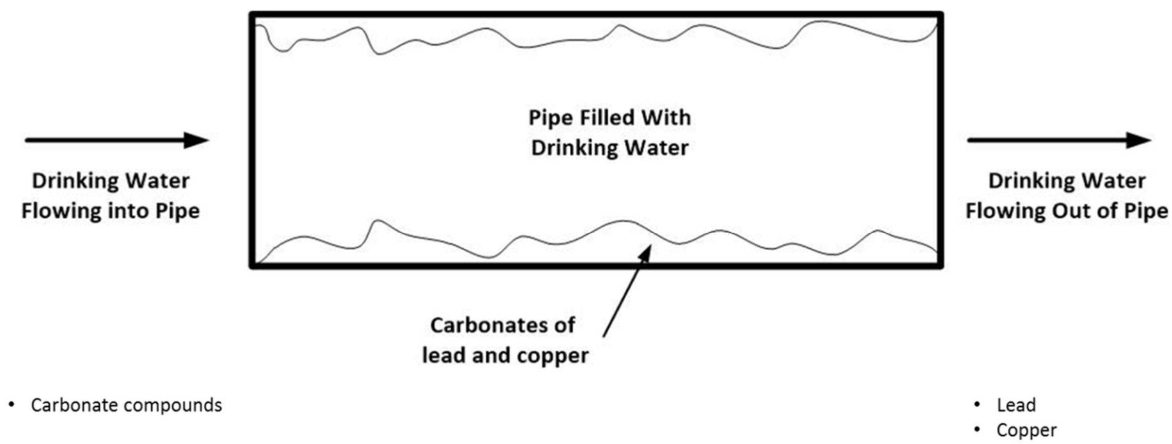

Figure 2.6 Regulatory Perspective of Lead and Copper Release

With this perspective, pH and alkalinity (a measure of carbonate concentration) can be altered to create a more insoluble lead and copper carbonate compound. The more insoluble the compound, the less likely lead and copper are to dissolve in the water. See Figure 2.7.

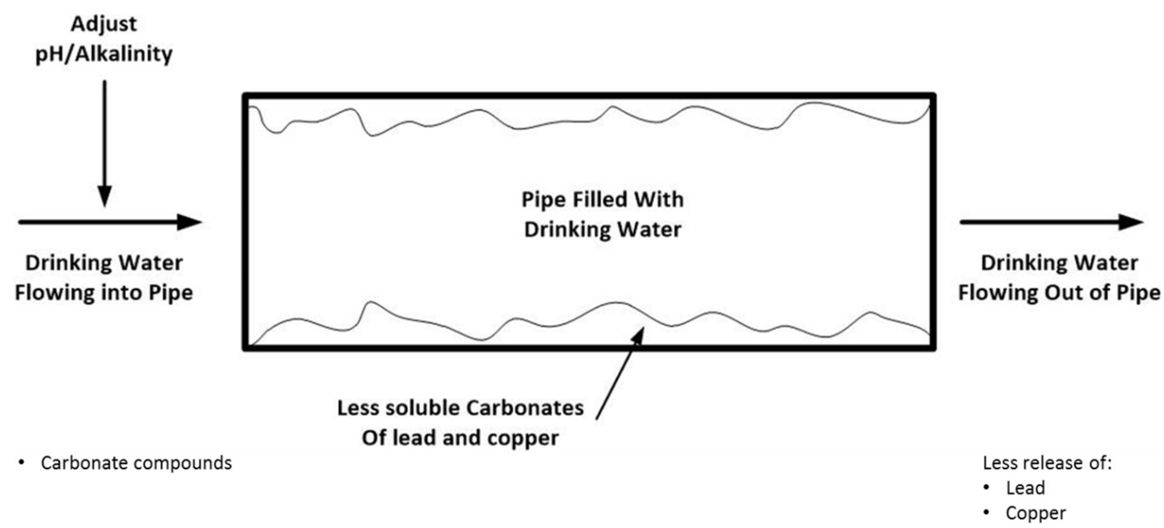

Figure 2.7 Regulatory Solution to Lowering Lead and Copper Release (Option 1)

Another regulatory solution to lowering lead and copper release is to add orthophosphate to the water entering the pipes. The phosphates form highly insoluble compounds of lead and copper and hold the metals on the pipe wall, stopping the process that transfers them from the solid metal into the water. See Figure 2.8.

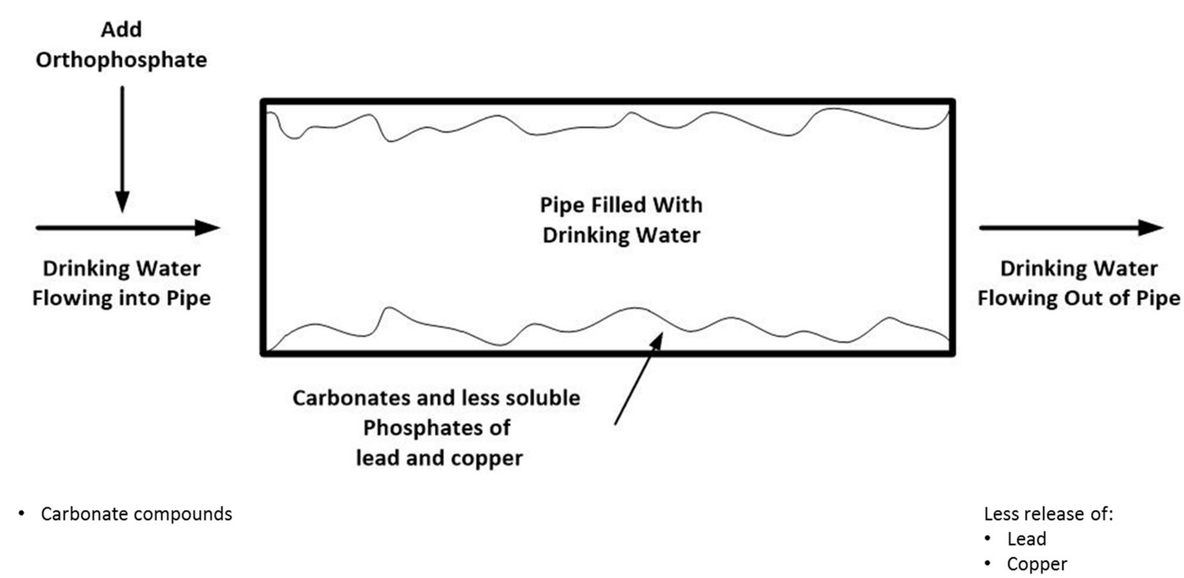

Figure 2.8 Regulatory Solution to Lowering Lead and Copper Release (Option 2)

This works in an ideal pipe with ideal water. Many of our aging water systems include the complex mix of chemical and microbiological components shown in Figure 2.3

making the regulatory solutions to lead and copper control diminished in effect or irrelevant in many cases.

With the comprehensive perspective of water quality, all distribution system problems, including lead and copper release, are addressed by cleaning out the complex mix of chemical scales and biofilms on the pipe walls. In addition, scale-forming chemicals, like iron and manganese that are known to capture and transport lead and copper around the water system, can be prevented from entering the distribution system. Also, it is important to achieve “biostability” of the water in order to limit the effects of the natural presence of microorganisms on water quality. Biostability refers to balancing factors that encourage the excessive growth of microorganisms with those that discourage their growth. Nutrients for microorganisms (carbon, nitrogen, and phosphorus) can be lowered in concentration and disinfection can be added within an appropriate concentration and pH range to prevent excessive microbiological activity. See Figure 2.9. The outcome is biologically stable drinking water flowing out of clean pipes with a low potential to develop water quality problems.

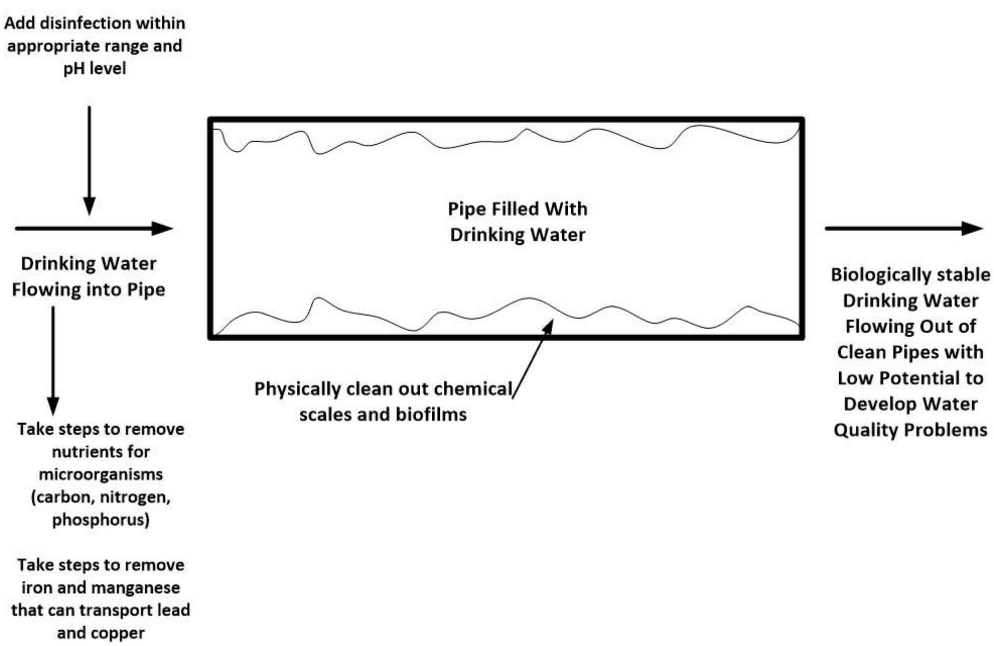

Figure 2.9 Comprehensive Solution to Lead and Copper Release and Interrelated Issues

All water systems are on a water quality continuum as shown in Figure 2.10. Water systems with cleaner pipes and tanks and biologically stable water have less potential to develop water quality problems like lead and copper release, presence of pathogenic microorganisms, disinfection by-products, etc. At the other end of the spectrum, there are “dirtier” water systems with many water quality ills where literally a “soup of metals and microbes” can be measured.

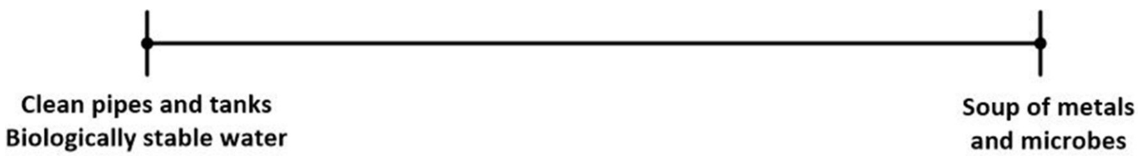

Figure 2.10 Water Quality Continuum

It should be noted that the comprehensive perspective of water quality ties together concepts that have been used in drinking water quality for many years but have not previously been put into such a unified order. Meeting current drinking water regulations does not go far enough to ensure appropriate water quality to consumers and their building piping systems.

This report assesses the Weston water system using three categories of factors that are representative of the comprehensive perspective described in this section. The categories are:

- Factors that affect the uniform corrosion of metals
- Factors that affect microbiologically influenced corrosion and the biostability of water
- Factors that affect the formation and dissolution of chemical scales throughout the distribution system

These concepts are explained further in Water Research Foundation Report 4586, referenced earlier, and will not be repeated in this report.

Section 3: History and Timeline

The Village of Weston water utility was established in 1968. Currently, the Weston water system includes five wells. The Bloedel well (Well 5) and the Alta Verde well (Well 1) are located on the west side of the Village. There is reduced usage of Well 5. The Mesker well (Well 3) and the Sternberg well (Well 4) are located on the east side. The Rippling Creek well (Well 6) is located at the northern boundary of the Village. The two east side wells (3 and 4) flow to an air stripper for removal of volatile organic carbon compounds. There is also a sixth well (Well 2) that only serves the Foremost Dairy and is isolated from the rest of the Weston water system. Table 3.1 summarizes the wells and their characteristics.

Table 3.1 Village of Weston Wells

Well Name	Well ID	Depth of Well in Feet	Casing Diameter in Inches	Yield in Gallons per Day
Alta Verde	1	78	12	864,000
Foremost	2	70	16	1,000,000
Mesker	3	92	20	1,440,000
Sternberg	4	83	20	1,440,000
Bloedel	5	85	20	1,296,000
Rippling Creek	6	111	16	812,000

For water storage in the system, the capacity is:

- Clearwell at the water treatment plant – 100,000 gallons
- Summit Tower – 100,000 gallons (It was proposed in 2003 that this tower be abandoned and replaced with a new structure nearby with a capacity of 500,000 gallons. This was listed in a capital improvement plan in 2017.)
- Everest Tower – 250,000 gallons
- Business Park Tower – 500,000 gallons (This tower was proposed in 2002 and was constructed in 2005.)
- Foremost well tower – 100,000 gallons (This tower is isolated from the Weston water system. It receives water from the Foremost well and feeds the dairy and a nearby regional wastewater treatment plant.)

The water system consists of over 100 miles of water main with asbestos cement and cast-iron pipe used in the northwestern quadrant of the Village and mostly ductile iron pipe in the remaining sections.

A new well (Well 7) was proposed in a 2017 capital improvement plan along with the replacement of the Summit Tower. In addition, manganese removal was proposed for the Bloedel well (Well 5). Facilities upgrades were proposed for the Sternberg and Alta

Verde wells. For future consideration is an iron and manganese removal facility at the Foremost Dairy well and the retirement of the air stripper.

There is chemical treatment of the groundwater at all wells. A polyphosphate/ orthophosphate blend (Aquadene 7101) has been dosed since the establishment of the water system; the intent is to sequester iron and manganese that is carried by the well water. Sodium hydroxide is dosed to keep the pH at around 7.7 as the well water tends to have a pH below 7 that is corrosive to metals. Chlorine has been dosed as sodium hypochlorite from the establishment of the water utility. Originally, the dosage goal was between 0.1 to 0.3 mg/L. This is considered a lower dose by today's standards.

There have been water quality studies performed in the past. In May 1980, it was discovered that the asbestos-cement water main interiors were deteriorating, becoming soft and releasing asbestos into the water. In June 1982, a study with the U.S. Environmental Protection Agency on the deterioration of asbestos-cement piping was performed, but the recommended addition of zinc orthophosphate did not solve the issue.

In September 1982, Strand Associates was hired to determine how to treat the water to not only stabilize the asbestos-cement pipe but also to control high iron and "red water" issues in the distribution system. The system water, in general, was termed "corrosive". That appears to be from the fact that there was a low Langelier Index and Aggressiveness Index. This indicated that the water had a tendency to dissolve calcium. With the cement piping containing calcium, the cement would have a tendency to dissolve and release asbestos fibers. The report also noted that the use of polyphosphate as a means to sequester iron in the water, may be softening the cement pipes. This is plausible because polyphosphate has a tendency to sequester calcium as well as iron, pulling it into the water from the piping. As stated above, a 1982 treatment of adding zinc to the water had been attempted but that did not stabilize the pipe. It was theorized by Strand that the polyphosphate interfered with the zinc's ability to participate in the cement's structure. The use of zinc orthophosphate to replace the polyphosphate product was proposed for study as it would provide the zinc for the cement treatment as well as orthophosphate for control of iron corrosion. A pH elevation was also proposed in order to increase the Langelier Index, indicating less of a tendency to dissolve calcium. In addition, iron and manganese removal by aeration and filtration was considered to replace the polyphosphate sequestration as an option if the zinc orthophosphate did not completely remedy the red water issue. None of the recommendations were implemented.

In June 1995, a water quality report by Becker-Hoppe Engineers noted that organic carbon concentration in the distribution system could be found at levels higher than seen at the entry points to the distribution system. They theorized that this was a result of microbiological growth and die-off in the water system. They also discussed the signs of increased bacteria populations such as in the extremes of the water system. The Mesker Well, which was routinely injected with polyphosphates for cleaning, underwent routine sampling of heterotrophic plate count where results could be found at greater than 20,000 CFU/mL (less than 500 is considered the norm). Iron bacteria were identified as excessively present in the water system. The report also noted chemical feed equipment malfunctioning with inconsistent feed rates. In addition, the use of multiple wells created areas of differing water quality characteristics, sometimes insignificant but sometimes significant in effect. The report also noted the lack of pH control with the low alkalinity which could be remedied with the use of soda ash (sodium carbonate) for both pH and alkalinity adjustment instead of caustic soda (sodium hydroxide) for pH adjustment only. The report also acknowledged that too high a pH would render the chlorine disinfection ineffective. It was suggested to use soda ash to stabilize alkalinity and pH and to continue the use of the current phosphate product for lead and copper corrosion control. It was also suggested that iron and manganese removal facilities be added for the Mesker well.

In a memo written by Mark Thompson, the director of the utility at the time, there was a response to the Becker-Hoppe report. The use of soda ash was discouraged because of the operational problems of mixing a solution for dosing. The chemical had been tried in the system but the operational issues were too much to overcome. The installation of iron and manganese removal at the Mesker well was rejected because the well was under threat from landfill contaminants at the time. The idea of upgrading chemical dosing equipment was accepted and it was suggested that new wells be sited.

In the 1990's, Wells 3 and 4 were found to be directly down-gradient from a leaking underground storage tank. Both a remediation system for the groundwater near the tank and an air stripper for Wells 3 and 4 were installed to keep the volatile organic carbon compounds out of the drinking water. Eventually, Well 4 was taken off-line. Around 1998, the groundwater remediation system was taken off-line. Well 4 was placed back in service. The water from Wells 3 and 4 continue to be treated in the air stripper. There is a proposal to decommission the air stripping treatment in the near future as the threat from the leaking tank has diminished.

In 2008, there was an investigation of a house with pitting of metal fixtures. A laboratory analyzed water samples and claimed that there was no issue with the water. They suggested that cleaning agents were destroying the metal. This should be re-visited using the comprehensive perspective of water quality described in Section 2.

Water system events over the past five years have included:

- 2013 the Foremost well was taken off line and the dairy supplied with water from the Village of Rothschild's system. (Note: Whenever the Foremost well is taken off-line for maintenance, possibly every two years, the Foremost Dairy receives water from the Village of Rothschild water system.)
- 2014 This was a very cold year where pipes froze. There were many main breaks and frozen service lines. This occurred throughout Wisconsin.
- Also, in 2014, the Foremost well was placed back on-line, there was a lot of distribution system valve repair, and a uni-directional flushing plan was developed on paper for the Village of Weston.
- In 2015, the Foremost well was off-line again. There were also expenses for the chlorination systems for the Foremost and Alta Verde wells.
- In 2016, Well 5 underwent screen cleaning and pump maintenance.
- In 2017, similar rehabilitation has begun on Well 6.

Future changes anticipated for the water system are:

- For Well 5, iron and manganese removal is anticipated. In the service area of Well 5, there are complaints regarding black water and deposits on fixtures. One particular coffee shop in the area is in the middle of such a water quality issue.
- The removal of the air stripping process is possible in the future. The groundwater near Wells 3 and 4 has been sampled for about 30 years because of a leaking underground storage tank at a gas station nearby discovered in the late 1970's or early 1980's. The sampling was also related to a nearby landfill. The sampling effort has been reduced over the years as the groundwater pollution has stabilized. The air stripper for Wells 3 and 4 may no longer be necessary.
- Well 7 is being planned for construction in 2018 or 2019.

The historical timeline of the Weston water system can also be viewed through the Lead and Copper Rule compliance sampling. Figure 3.1 shows the compliance sampling results for lead and for copper. Weston does not have lead service lines, so lead levels are relatively low. However, lead does exist in the water system because of the use of lead in metal alloys installed in the past, mostly within private plumbing systems. Copper, also shown in Figure 3.1, is found to be lower than the Action Level for the Lead and Copper Rule. However, other Wisconsin water systems display copper concentrations between 50 and 100 µg/L. Therefore, the copper concentrations are slightly elevated but not at a level to be concerned regarding consumer health. The slight elevation can be seen as cautionary regarding the potential for metals corrosion in the water system. In Figure 3.1, it is good to see that there is a decreasing trend for the 90^{th} percentile copper concentrations.

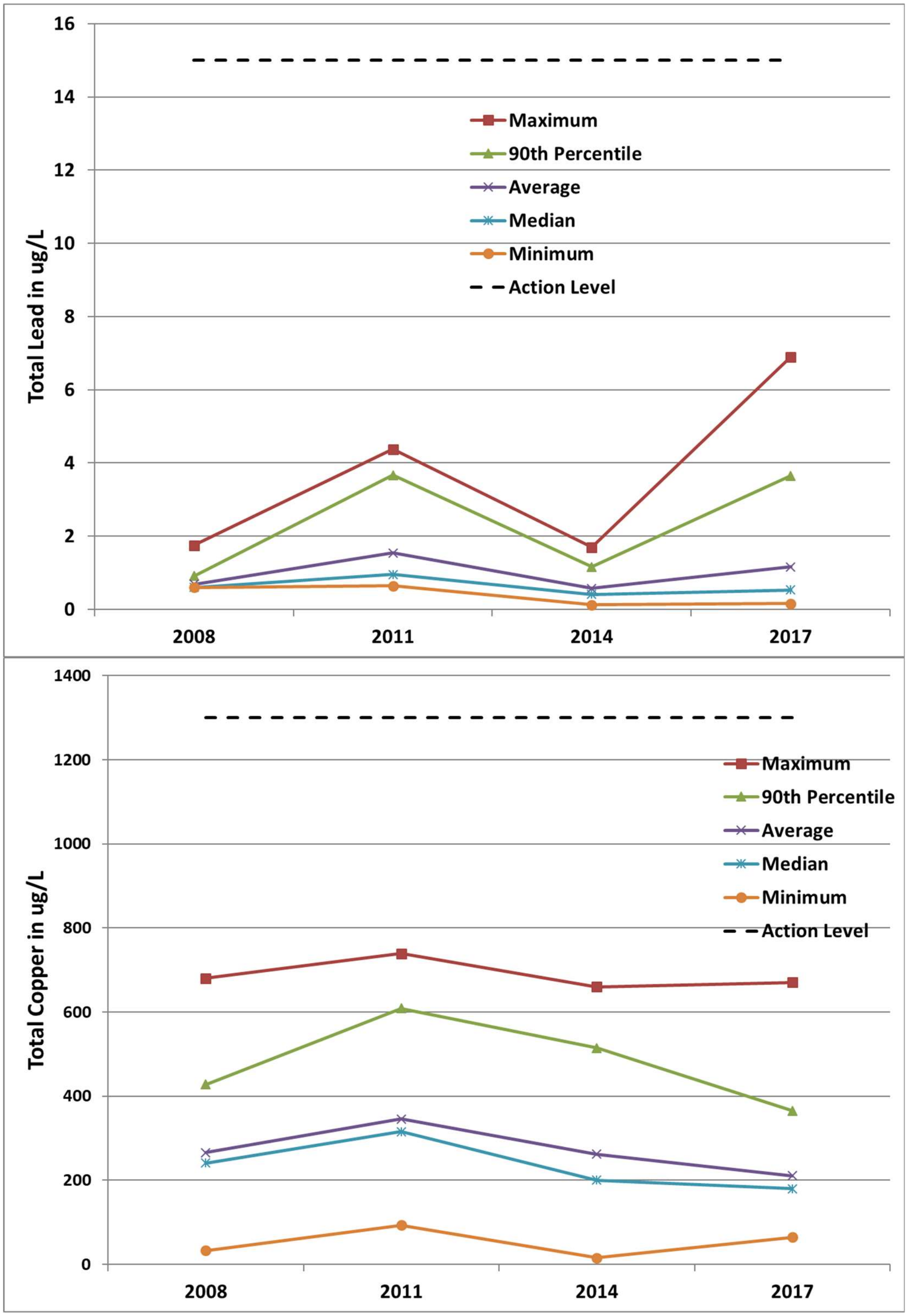

Figure 3.1 Lead and Copper Rule Compliance Sampling Data

Section 4: Factors that Affect the Uniform Corrosion of Metals

Figure 4.1 shows a map of water quality developed by Becher-Hoppe engineering company in 1995 of the Weston well water and some distribution system sites. The map shows that water from the wells has low alkalinity, around 50 mg/L as CaCO3. The pH of the well water can be below 7.0.

The pH goal should be above 7.0 in order to prevent corrosion of metals, as they can corrode in such acidic water. However, the pH should not be pushed above 7.7 because the effectiveness of free chlorine disinfection is diminished as the pH increases. In addition, the pH needs to be elevated in order to prevent the dissolution of calcium from the cement and the cement-lined piping. To satisfy all three criteria, the pH of the water should stay around 7.7, the current pH goal.

However, pH control is not easy in low alkalinity water. Alkalinity is defined as the ability to buffer the water and stabilize the pH. This is the reason that past suggestions of lime or soda ash addition, which adds carbonates to the water that can buffer against pH changes, were made.

Alkalinity is also somewhat synonymous with carbonate concentration. Typical pipe wall accumulations that can slow down the uniform corrosion process are composed of metal and carbonate compounds that form on metal surfaces. Lack of carbonate concentration (low alkalinity) can lead to higher uniform corrosion rates.

Data on chloride concentrations from the wells were obtained from the Wisconsin Department of Natural Resources (WDNR). Although there is not much data recorded over the years, it appears that chloride concentrations have increased in the well water over time. Some measurements made in 2017 show chloride above 200 mg/L. Chloride is very corrosive to metals. It forms compounds with metals as they are released from metal surfaces during the electrochemical uniform corrosion process that occurs naturally. The chloride and metal compound that is newly formed is highly soluble. The uniform corrosion process is perpetuated as the chloride and metal compounds are whisked away from the corrosion sites by the flowing water. Many water systems are experiencing increased chloride concentrations in source water from the use of road salt in winter.

Nitrate is another compound that can form highly soluble compounds with metals. Just like chloride, it can participate in perpetuating the uniform corrosion of metals. Nitrate can enter groundwater from agricultural sources. It can also be created in water systems by microorganisms that transform ammonia into nitrate. WDNR data show slowly increasing nitrate concentrations in the well water.

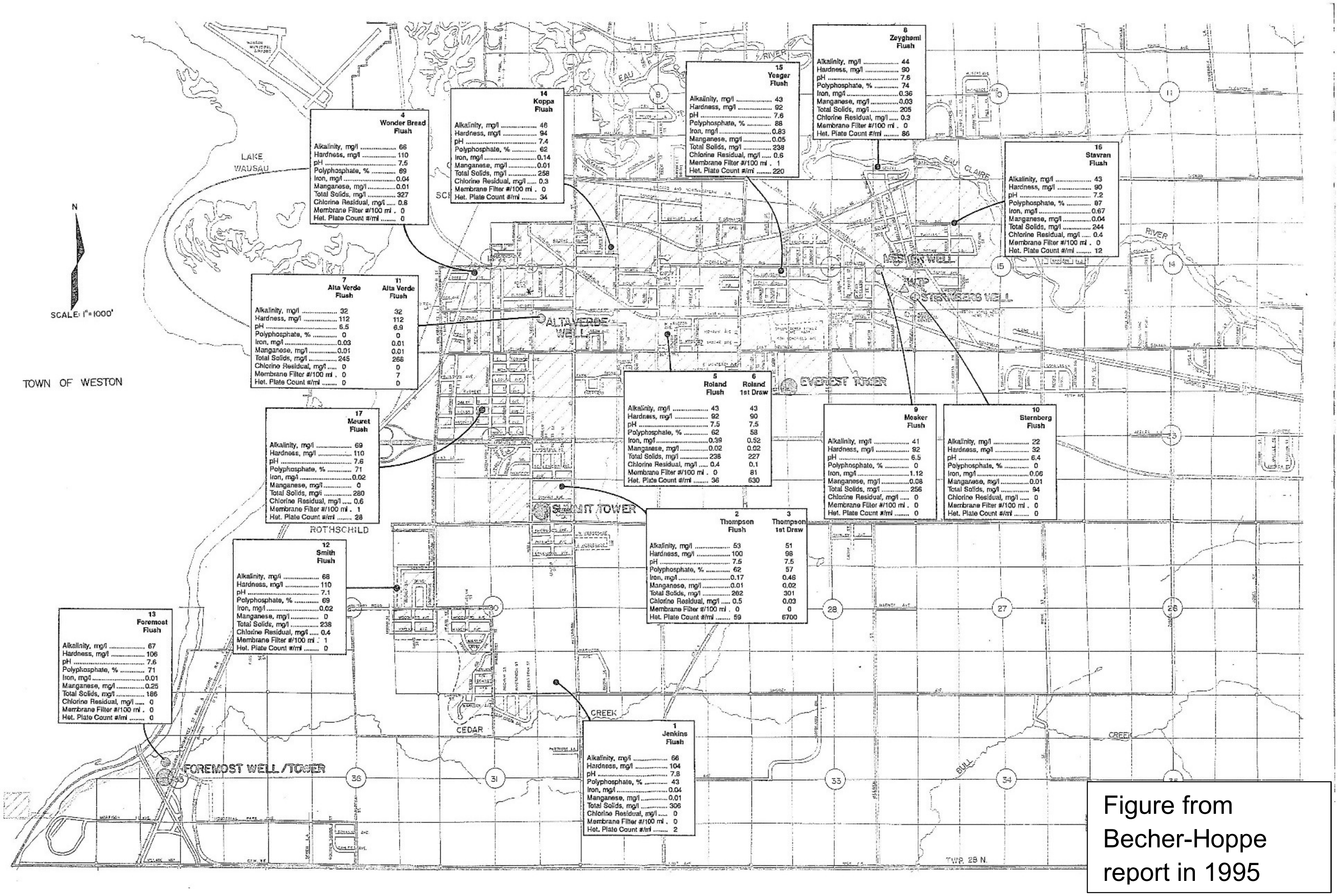

Figure 4.1 Map of Drinking Water Quality for the Village of Weston from a 1995 Report

The addition of polyphosphate to sequester iron and manganese in the water system can have negative side effects. While the chemical can clear up the color of the water, iron and manganese are held in the water and ingested by the consumers of the water. Other metals, such as lead and copper, can be held in the water as well and consumed. And, as mentioned in the 1982 Strand Associates report, the polyphosphate also sequesters calcium and can affect the integrity of the cement piping.

In summary, low and unstable pH, the presence of chloride at higher levels, and increasing nitrate levels are three reasons why the well water in the Weston water system would tend to be corrosive to metals, including iron, manganese, copper, and calcium. The addition of polyphosphate further brings metals into the water from accumulations on the pipe walls.

Section 5: Factors That Affect the Formation and Dissolution of Chemical Scales

Figure 4.1 also shows the water quality at points within the distribution system. As the 1995 Becher-Hoppe report points out, mixing of water from various wells creates varying water quality properties throughout the distribution system. Fluctuating pH and alkalinity and other factors can cause release of existing accumulations on pipe walls. The accumulations include compounds protective against metals corrosion and also chemical scales of iron and manganese.

Iron and manganese scales can lead to discolored water in private buildings. The Village of Weston has been flushing the water mains in order to remove these scales. Water samples are taken before and after flushing at designated locations as shown in Figure 5.1. (Sites with identification numbers above 16 are not shown on this map.)

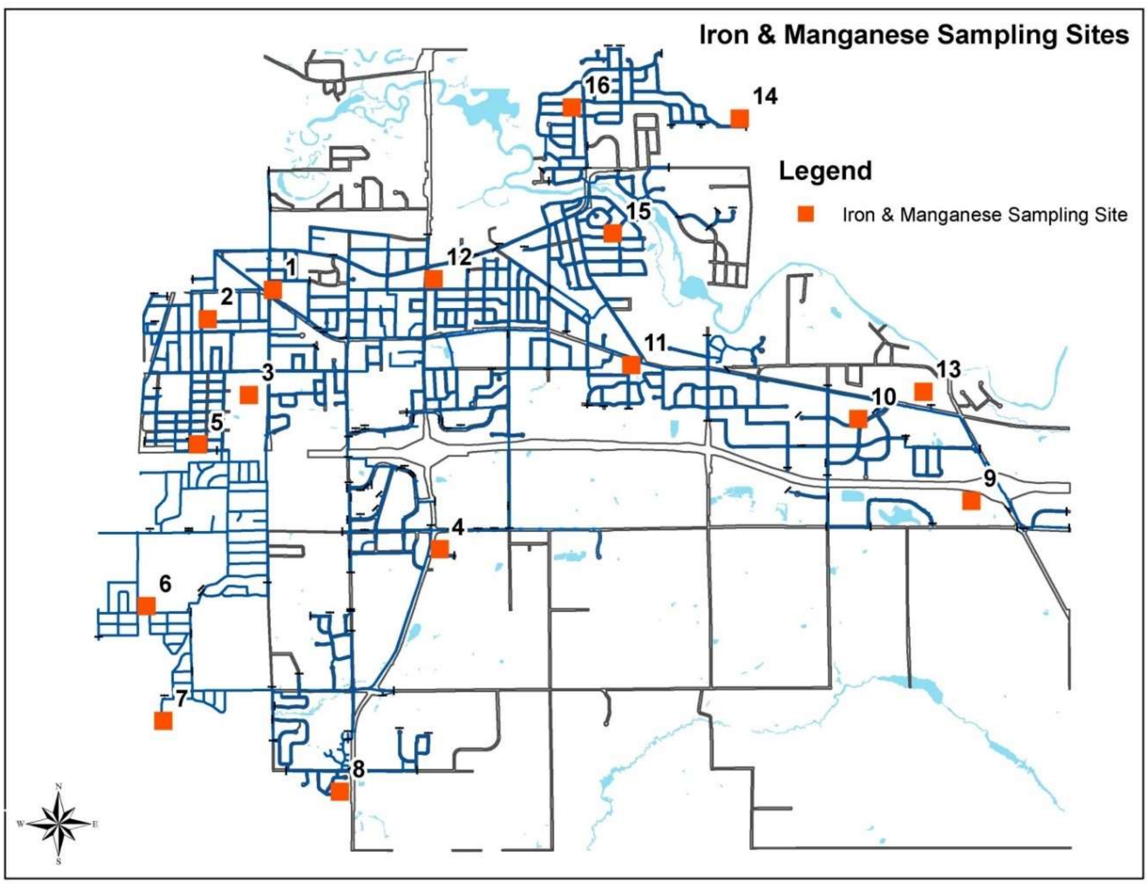

Figure 5.1 Map of Distribution System Sites for Monitoring Before and After Water Main Flushing to Remove Iron and Manganese

Data from the distribution system sampling sites on Figure 5.1 are shown in Figures 5.2 and 5.3. From flushing seasons in 2010 to 2012 shown in Figure 5.2, the iron concentration in the water appears to have been lowered over time. The dashed line on the graph represents the non-enforceable aesthetic level for iron in water at 0.3 mg/L. There are sites that have remained above that level. There was also a period of time in 2011 with very high random iron levels. Also shown on Figure 5.2, manganese exhibited similar behavior with some sites routinely over the aesthetic level as well as random peaks of manganese concentration. There was a distinct system-wide disturbance of manganese around September 12, 2012. One explanation for the higher peaks of iron and manganese is the occurrence of hydraulic events, such as main breaks or flow reversals. However, flushing for water main cleaning, itself, is a hydraulic disturbance. If flushing is discontinued in a pipe segment before the number of particulates (as measured by turbidity) is very low, the iron and manganese scale particles may remain entrained in the water.

Figure 5.3 shows pH and free chlorine concentration taken at the same time as the iron and manganese measurements. Comparing shapes of graphs between Figures 5.2 and 5.3, there does not appear to be correlations between the four water quality parameters. In Table 5.1, the same parameters are compared in a second way. The average of each parameter over the 2010 to 2012 time period was calculated and then the sampling sites were arranged in order of increasing averages for each parameter. If there were correlations between the water quality parameters, one would expect to see similar orders or opposite orders of sites in the Table 5.1 lists. It does not appear that pH and chlorine concentrations are directly related to total iron and total manganese concentrations at the sampling sites.

Data are also shown in Figures 5.4 and 5.5 for flushing during 2017.

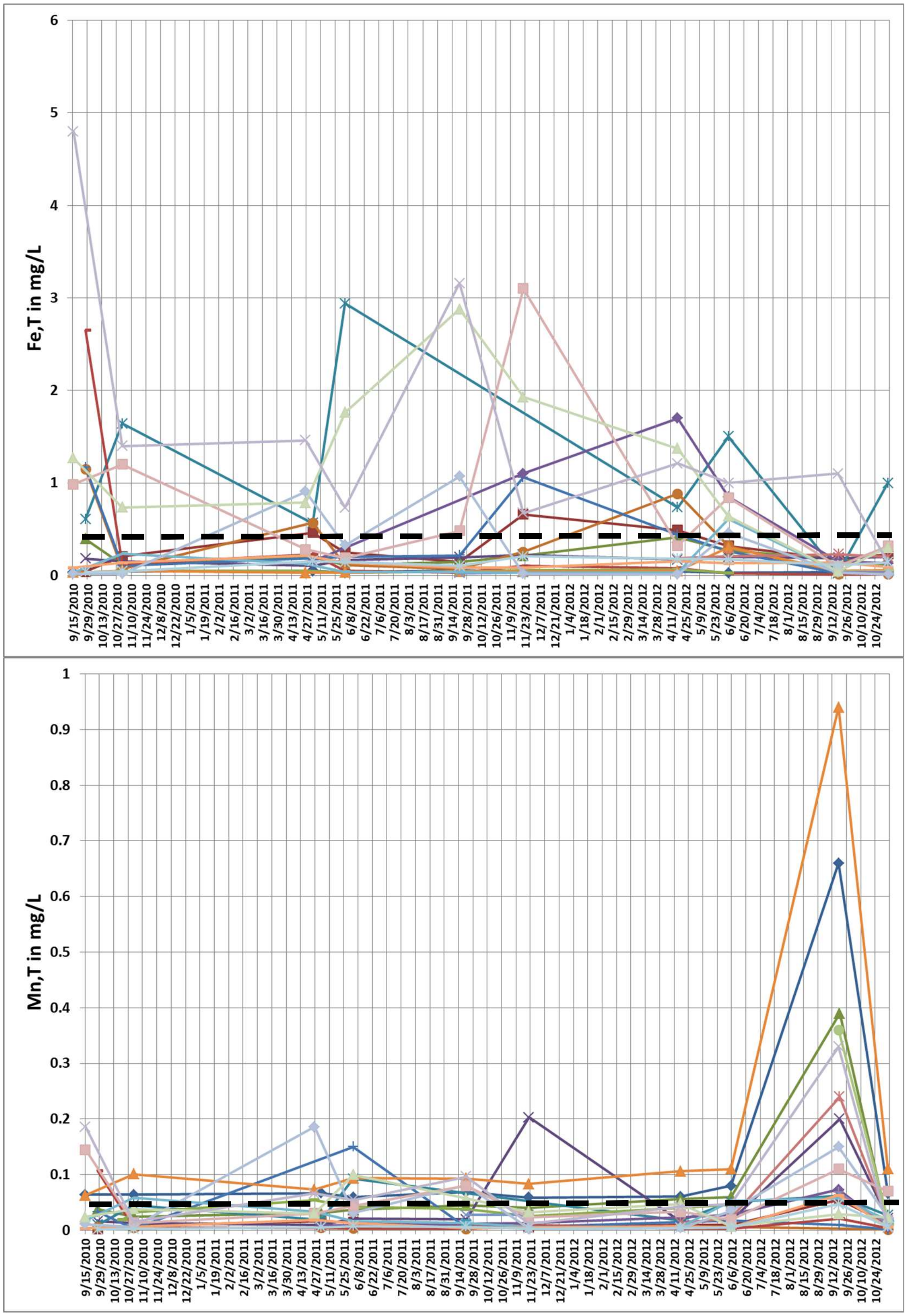

Figure 5.2 Iron and Manganese Measured at Distribution System Sites 2010 to 2012

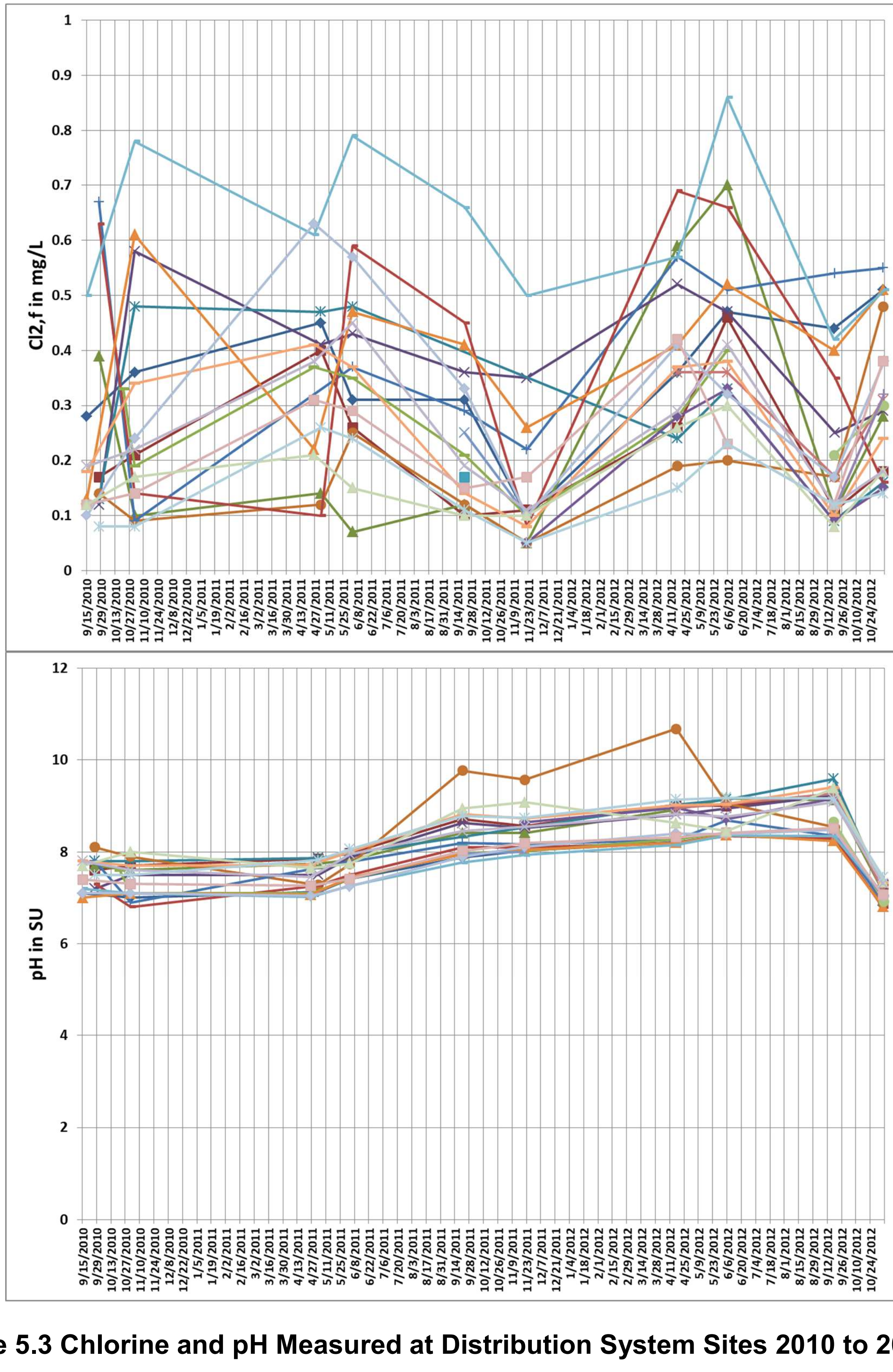

Figure 5.3 Chlorine and pH Measured at Distribution System Sites 2010 to 2012

Table 5.1 Water Quality Parameters at Distribution System Sites: 2010 to 2012 Lowest to Highest Results Listed as Site Number from Figure 5.1

Free Chlorine	pH	Total Iron	Total Manganese
9	3	1	14
7	1	17	9
18	2	2	4
14	16	3	10
10	5	4	16
6	17	9	18
8	6	12	3
11	15	21	15
4	12	11	17
17	8	5	7
13	11	10	13
21	7	16	5
5	13	14	12
1	10	15	6
12	9	18	21
16	4	6	11
2	14	13	8
15	18	7	1
3	21	8	2

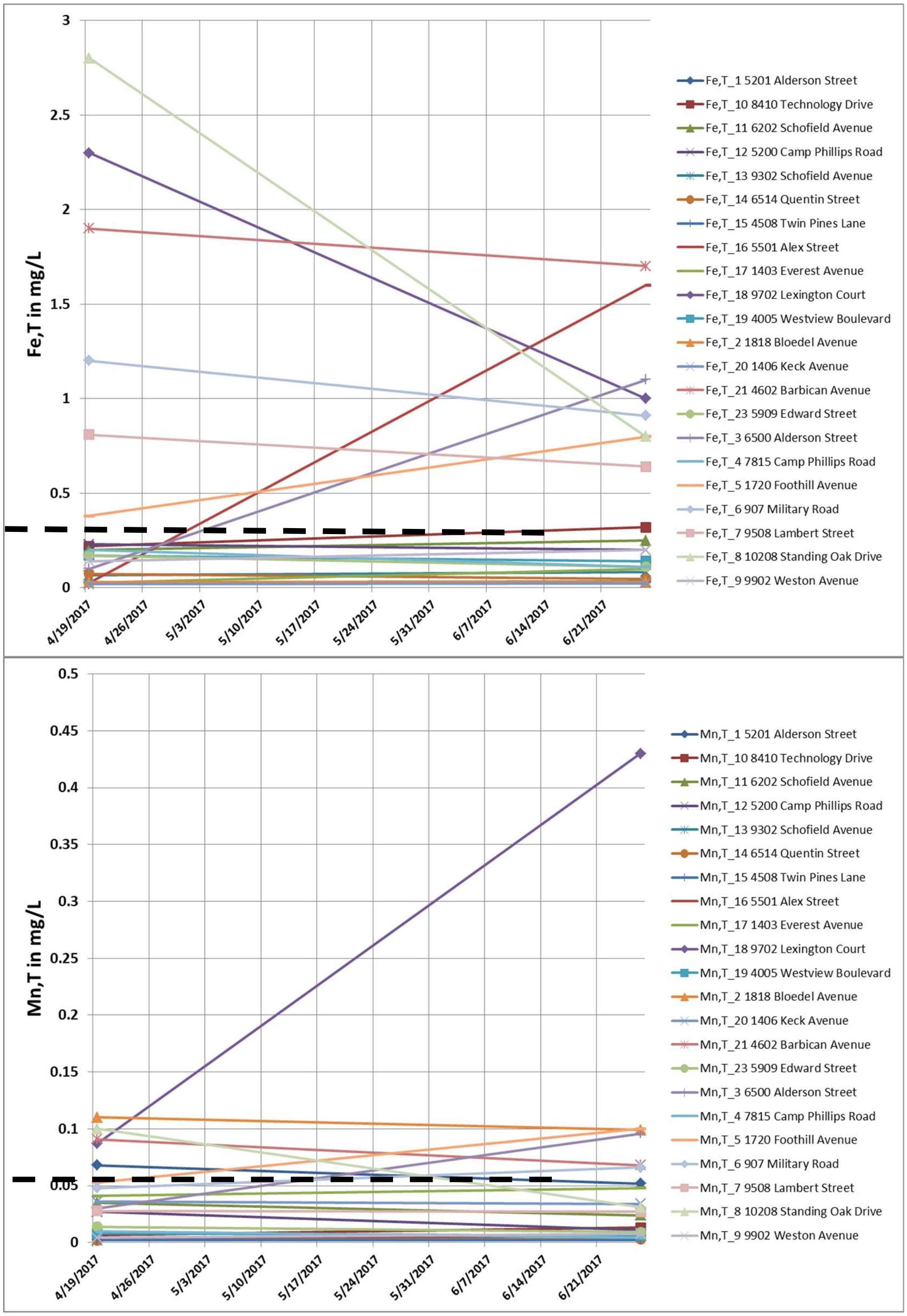

Figure 5.4 Iron and Manganese Measured at Distribution System Sites 2017

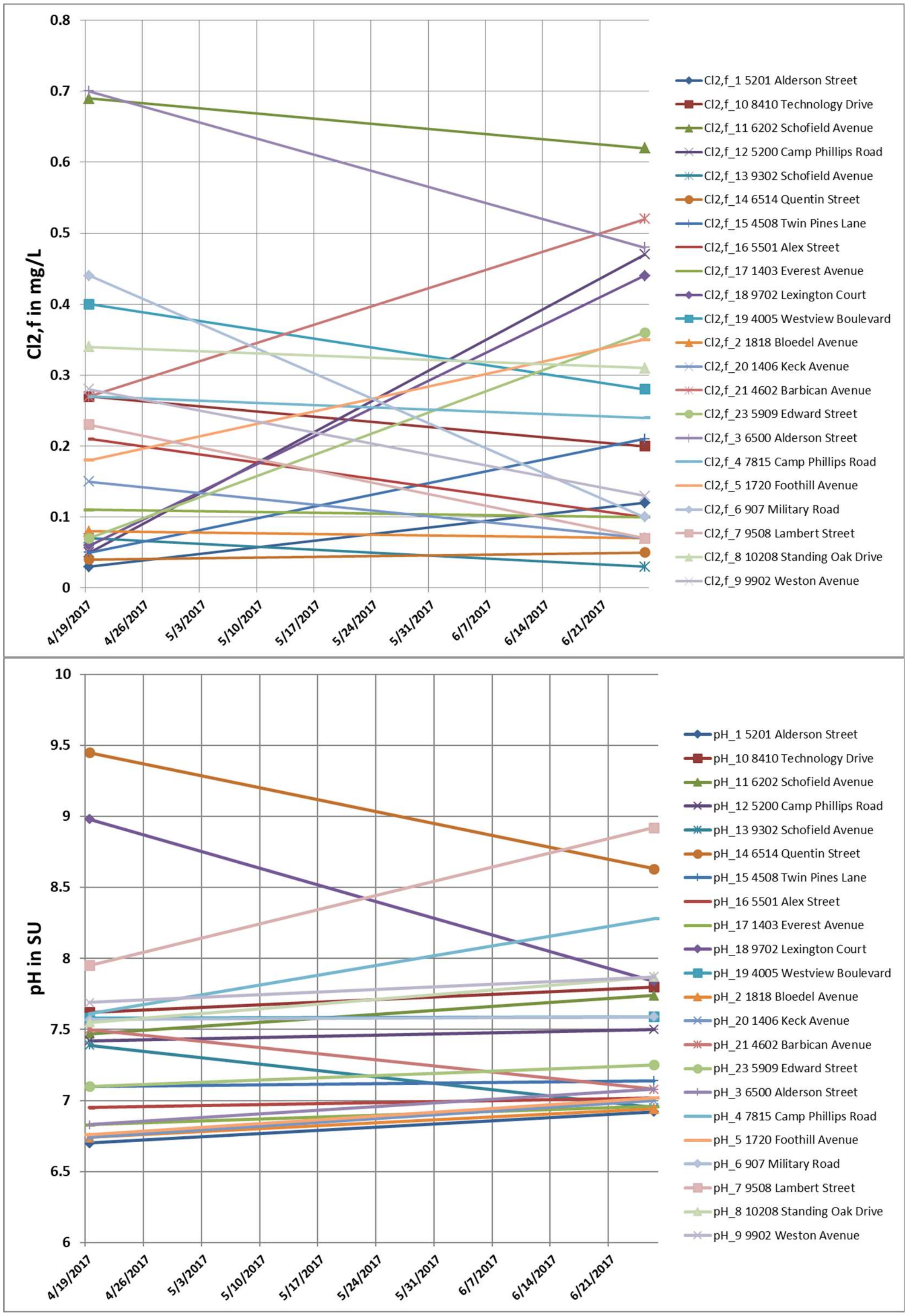

Figure 5.5 Chlorine and pH Measured at Distribution System Sites 2017

Section 6: Factors that Affect Biostability of Water

Biostability of water is the balance of factors that encourage the excessive growth of microorganisms with factors that discourage their growth. Factors that encourage their growth are the presence of nutrients (carbon, nitrogen, and phosphorus compounds) and high residence time of water in a water system. Factors that discourage their growth are higher disinfection concentrations, low residence time in the water system, and lack of nutrients.

It is desired to limit microbiological growth because they can cause many water quality issues. Water quality issues that can be caused by microorganisms are:

- Increased use of disinfection in the distribution system
- Greater potential for the growth of microorganisms that can make people sick, such as E. Coli and Legionella
- Greater potential for the formation of disinfection by-products with increased production of carbon compounds by microbiological growth combining with disinfection chemicals
- Microbiologically influenced corrosion of metals because of production of microbiological metabolic waste-products, such as nitrates and acetates, and acidic chemicals
- Greater potential for tastes and odors in the water

In this study assessing existing information, disinfection concentrations taken routinely at Total Coliform Rule sites were graphed over time to look at trends at each site. An Excel® spreadsheet of the graphs is available to look for particular times and locations that the disinfection concentration may have been low. Low concentrations indicate that more material is present to react with the disinfection, either chemical scales or microbiological materials. Low concentrations can also indicate a malfunctioning of dosing equipment. These graphs can trigger troubleshooting activities that can lead to operations improvements.

A summary of graph information is shown in Figure 6.1. Each sampling site is associated with a red square on the graph which is the average of the disinfection concentration over a time period. In Figure 6.1, two time periods of data are shown, data taken in 2016 and data taken in 2017. The “whiskers” attached to the red square shows the range of concentrations that, statistically, 99% of the data are expected to fall. In this way, the variation of the disinfection concentration at each site is shown. It is desired to have an average concentration above 0.3 mg/L free chlorine with a very narrow variation. The graphs can be found to determine which sites meet that criteria and which do not.

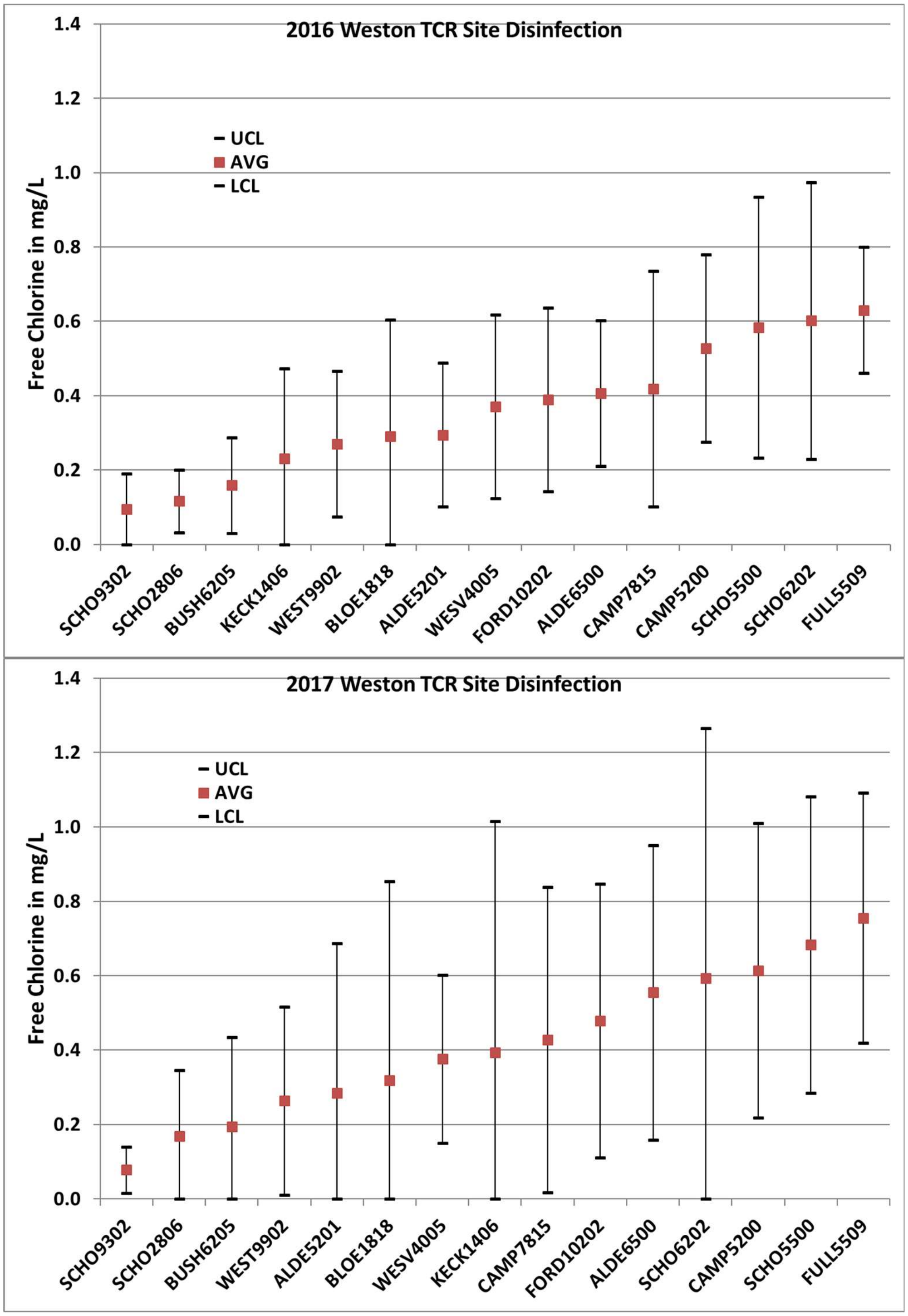

Figure 6.1 Disinfection Concentrations at Total Coliform Rule Sites Compared from Site to Site and Between 2016 and 2017

Another indicator of microbiological activity in the distribution system is disinfection by-product concentrations. This is also data taken routinely for regulatory purposes. Graphed over time, certain patterns can emerge. Microbiological materials can combine with chlorine disinfection and form these compounds. While some or all of the carbon that makes up these compounds can come from the source water, some or all of it can also come from materials created in the distribution system by microorganisms. The group of disinfection by-products called total trihalomethanes (TTHM) shown in Figure 6.2 shows an increase over time since 2000. The group of disinfection by-products called halo-acetic acids (HAA5) also shown in the figure appears to have suddenly increased in 2014. These patterns can reflect the growth of particular microorganisms in the water system, those that produce methane as a waste product and those that produce acetic acid.

In summary, there are indications that there is a microbiological aspect to water quality issues in the Village of Weston water system. This was noted in the 1995 water quality report. Current clues to a microbiological aspect are reports of toilet tank materials buildup, corroding anode rods in hot water tanks, tastes and odors complaints, locations of low disinfection concentrations, and patterns of disinfection by-products.

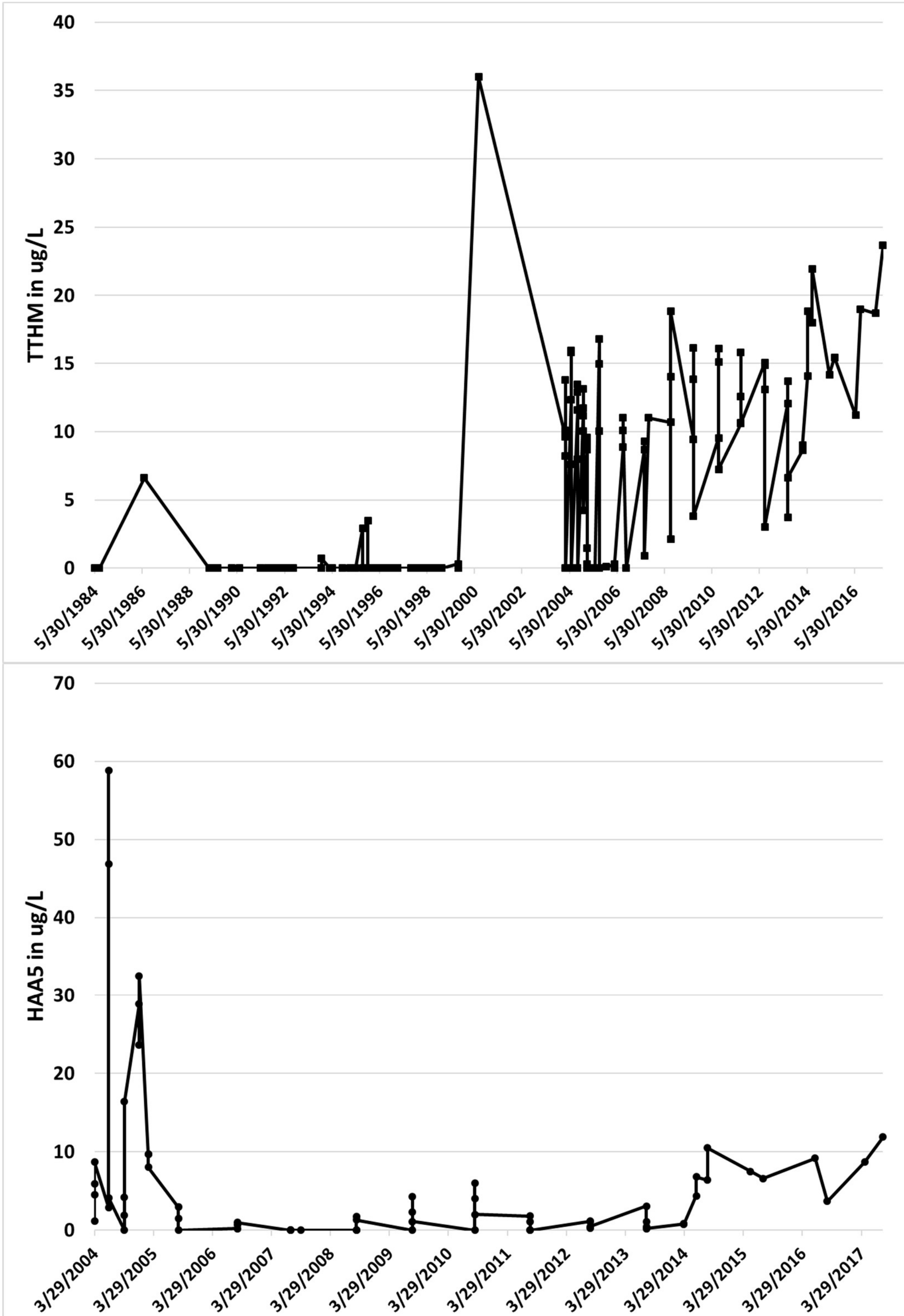

Figure 6.2 Disinfection By-products in the Village of Weston Water Over Time

Section 7: Conclusions and Recommendations

CONCLUSIONS

There are indications in the Village of Weston water system of the presence of “metals and microbes” as described in Section 2 regarding the comprehensive perspective of water quality. There are many water systems with this type of drinking water environment because water quality has not been studied with a comprehensive understanding in the past. The Village of Weston is not unique in this regard. Just like many of the other water systems with this drinking water environment, the drinking water is in compliance with Federal primary drinking water regulations. In this section, there are recommendations to go beyond the requirements of the drinking water regulations and achieve a balance of water quality parameters that lowers the potential for aesthetic, infrastructure integrity, and health-threatening problems to occur.

To summarize the issues in the Weston water system, there are complaints of discolored water from iron and manganese and discolored materials building up on fixtures. Foremost Dairies reports corrosion of heat exchangers with high chloride levels as a suspected factor. There is a history of dissolution of calcium from cement pipes. There are observations of microbiologically influenced activity such as corrosion of hot water tank anodes, increased organic carbon in the distribution system, and increases in disinfection by-products.

In studying existing data and engineering reports, it is found that:

- The wells provide water with low alkalinity and low pH.
    - Low pH below 7.0 leads to corrosion of metals
    - Low alkalinity leads to unstable pH which can vary to lower levels even when boosted by caustic soda
    - Low alkalinity leads to inability to provide carbonate to aid in forming films on metal pipe walls that can lower the rate of metals corrosion
    - Low pH leads to dissolution of calcium from cement and cement-lined piping
- The wells provide water high in chloride concentrations
    - High chloride concentrations promote the corrosion of metals
    - A major source of chloride found in source water is from the use of road salt. Shallow wells, such as those found in Weston, are susceptible to road salt intrusion.
- The wells provide water with slowly increasing nitrates
    - Nitrates promote the corrosion of metals.
    - Nitrates in source water can come from agricultural runoff

    - Nitrates in source water and in the distribution system can also come from microbiological conversion of ammonia to nitrate
- The wells provide water with elevated iron and manganese. The iron and manganese also precipitate and accumulate in the distribution system.
- Polyphosphate is used to sequester iron and manganese from the wells
    - Polyphosphate can also sequester other metals in the water system such as lead and copper.
    - Polyphosphate can sequester calcium from the cement and cement-lined piping
    - Polyphosphate can provide phosphorus for microbiological growth
- The potential for excessive growth of microorganisms and for microbiologically influenced corrosion is suspected
    - A 1995 water quality study identified increased organic carbon in the distribution system as well as high measurements of heterotrophic plate count and the presence of iron bacteria
    - Reported problems are similar to other projects that have been found to be microbiological in nature such as soft material deposited in stagnating water (such as toilet tanks) in buildings, fast corrosion of anode rods in hot water tanks, and increases in disinfection by-products in the distribution system

ASSESSMENT OF SPECIFIC BUILDINGS

There are two customer issues that began before this investigation and need to be resolved. A coffee shop in the vicinity of Well 5 reported that discolored deposits have built up in the toilet tank and in the main sink. The water department took samples from the toilet tank and the sink. A few additional samples should be taken:

- A metals scan at the sink faucet similar to the previous sample but under conditions of a six-hour stagnation
- Another stagnation sample to take at the same time is a special microbiological sample that measures the microbiological population in the water and also indicates the potential for biofilm formation.
- A microbiological sample should also be taken from the toilet tank.
- Finally, a microbiological sample should be taken at the kitchen sink faucet during flowing water conditions.
- The plumbing configuration of the coffee shop should be studied to determine if there are other critical locations in the plumbing system to sample and/or to maintain in a special manner so as to lower the potential for the problem to occur.

The Foremost Dairy has an issue with corroding heat exchangers. There are analyses that can be performed on the heat exchanger water and on the flowing influent water to the building that will characterize the chemical and microbiological interactions both in the heat exchanger and in the small isolated water system that supplies the dairy. In addition, the plumbing and water use configuration of the dairy should be studied to determine if there are other critical locations in the building piping systems to sample and/or to maintain in a special manner so as to lower the potential for metals corrosion to occur.

If there are any current complaints regarding corroding hot water tank anodes or hot water that has a sulfur smell or other bad odor, the building should also be investigated. Process Research Solutions has a technique for studying building plumbing that would be applicable in these cases.

The goal of these building investigations is not only to better define the problems in the buildings and suggest remedies but also to demonstrate and set protocols for how to respond to customer complaints.

WATER TREATMENT CHEMICAL ADDITION

Water treatment chemicals for disinfection and pH adjustment are used at the wells and are an important part of maintaining appropriate water quality in the water system. More tracking and control is needed to keep water quality consistent and to achieve the proper balancing of competing needs associated with each chemical.

Disinfection

Disinfection is necessary in a water system in order to control excessive growth of microorganisms in the distribution system. Typically, a minimum dosage of 0.3 mg/L free chlorine is the starting point for effective dosing and free chlorine dosing does not exceed 1.0 mg/L in most groundwater systems. In addition, when the organic carbon concentration in the source water is elevated or when there is excessive growth of microorganisms in the distribution system adding to the organic carbon concentration in the water, carcinogenic compounds can form between the chlorine disinfection and the organic carbon. These are called disinfection by-products. The formation of these disinfection by-products must be tracked and disinfection adjusted accordingly as well as measures taken, such as uni-directional flushing, to lower the organic carbon in the water system.

The operating parameters that are recorded every month at each well – the free chlorine concentration leaving the plant and the pounds of disinfection chemical per 1000 gallons of water treated – should be tracked routinely on a graph. There are also some special graphing techniques that can define trends of disinfection chemical usage. These graphs will indicate if the average dosing is being kept steady and within a narrow variation. If it is not, troubleshooting of operations should occur immediately. In addition, a routine of disinfection by-product measurement should be performed and graphed to detect excessive organic carbon concentrations or excessive chlorine usage.

pH Adjustment

Previously in this report, the importance of a steady pH was indicated in terms of controlling a number of chemical reactions and microbiological interactions in the distribution system. The only way that a low buffered (low alkalinity) water can hold a steady pH is to increase the alkalinity so that the water has more buffering capability. Past engineering reports have recommended the use of lime or soda ash in order to increase the alkalinity of the water. These are standard techniques for water treatment. However, operationally, the chemical addition is difficult to carry out as working with the dry chemicals to create slurries to feed into the drinking water causes many plugging and operational headaches. In the past, the personnel of the Weston water department expressed the impracticality of these methods in a small water system.

Therefore, a calcite contactor should be studied as an alternative method to increasing the alkalinity of the water. With this technology, a tank is filled with calcite (calcium carbonate) media. The water that is pumped from the well flows through the tank, picking up carbonate alkalinity and increasing the pH as it flows. Media replacement in the tank is, of course, dependent on the nature of the water and the loading volume of water per surface area in the contactor. However, the replacement frequency is on the order of about two times a year. The contactor should be designed to hold the pH around 7.7 and to increase the alkalinity enough so that the pH stays at that level or just below, if possible.

Operating parameters of pH and alkalinity entering the distribution system should be tracked and responded to as described for the disinfection chemical.

Phosphate Addition

A third treatment chemical currently in use in the Weston water system is the dosing of a polyphosphate chemical for sequestration of iron and manganese. This report has discussed issues surrounding the use of polyphosphate and it is recommended that iron and manganese be kept from entering the distribution system in the future so that the use of polyphosphate can be phased out.

The first step to lowering the iron and manganese levels in the distribution system is to determine if the metals are released in the wells by means of the corrosion of the well casing and associated wetted surfaces. In many cases, routine inspection, repair, and cleaning of wells can keep the iron and manganese lowered. This will be discussed below.

If the lowering of iron and manganese in the wells is not sufficient and it is found that the aquifer is inherently high in iron and manganese, then one or more treatment plants, typically aeration or oxidation and filtration under pressure from the well pump, will be necessary.

WATER TREATMENT PROCESSES

Air Stripping

It is desired to determine if air stripping is still required for Wells 3 and 4. Aquifer contaminant data from the leaking underground storage tank and the landfill must be studied to determine that. Existing hydrogeological studies of the situation must also be referenced.

Iron and Manganese Removal

Refer to the "Phosphate Addition" discussion above regarding iron and manganese removal.

SYSTEM MAINTENANCE PROTOCOLS

Well Maintenance and Cleaning

Determine if iron and manganese can be lowered by well maintenance and cleaning as a first step. Take samples from the wells, studying certain chemical and microbiological water quality characteristics at varying times of pumping. Sampling will first focus on Well 5 as a demonstration of sampling for the other wells.

The integrity of the well should be determined and repairs made to prevent the intrusion of water directly from the surface or from unintended underground sources. Water in the well column that is not refreshed routinely should be eliminated.

After this initial investigation there should be routine inspections, repair, and cleaning planned. Certain water quality parameters can indicate when a cleaning is required and they can be tracked over time.

The first step should be to sample the wells to determine their chemical and microbiological characteristics and to determine if iron and manganese concentrations are intensified within the well itself or if these metals are inherent in the aquifer.

Uni-directional Flushing

There is already a program of water main flushing in the Village of Weston. In Section 5, it was shown that the flushing activity is well orchestrated and monitored. Iron and manganese concentrations were lower in 2017 than in 2010 to 2012 most likely because of flushing efforts. However, it has been observed elsewhere that iron and manganese concentrations need to be greatly lower than the secondary limits of 300 µg/L and 50 µg/L, respectively, in order lower the potential for water quality issues that several buildings have experienced in the water system.

Uni-directional flushing (UDF) of water mains is a more effective method to cleaning accumulations from pipe walls in the distribution system than standard flushing methods. According to the technical literature, standard flushing riles up accumulations and does not necessarily remove them from the system. UDF uses a higher velocity of flushing water and scours the pipe walls. It is important to continue the flushing until the flushing water has a turbidity measured at less than 1 turbidity unit (NTU).

Storing data from each flushing run on beginning and ending turbidity, time to reach final turbidity, and velocity of water aids in streamlining the flushing process in subsequent cleaning periods. Costs and labor are higher for the first cleaning but decrease as the system becomes cleaner and the flushing data informs an optimized strategy of efforts.

When water mains no longer hold vast accumulations of chemical scales and biofilms, this material no longer becomes entrained in system water and no longer enters building plumbing systems. With the introduction of cleaner water to buildings, chemical and microbiological interactions lessen within building plumbing.

The current flushing program in Weston is one where there is the operation of valves to direct the flow of the water for flushing. The flushing program differs from uni-directional flushing in that flow rates are not verified and turbidity before, during, or after flushing are not measured. The Weston program is performed in the spring and fall of each year.

AECOM developed a uni-directional flushing program for the Village in 2014 using the computer hydraulic model for the water system. The program has not been implemented because of specific concerns with the high velocity release of water onto the ground and the streets. There should be a discussion to find a satisfactory protocol and the AECOM uni-directional flushing program should be implemented in the 2018 cleaning season. Turbidity should be measured at the beginning and end of each flushing run as well as other flushing run parameters as described in this report and as recommended by AECOM.

Consult AECOM about uni-directional flushing techniques with the asbestos-cement piping and the cement-lined ductile iron piping as the cement may require extra care during high velocity scouring activities.

Storage Tanks

Water samples should also be taken after each storage tank at times when the water has resided in the tanks for the longest periods. The samples should be analyzed for ATP and related parameters measured in the microbiology laboratory. They are analyses that describe the potential for the excessive growth of microorganisms in the drinking water.

SOURCE WATER PROTECTION

Control of Chloride

Initiate city- and county-wide plans to optimize the use of road salt. The chloride enters the source water and changes drinking water into water inherently corrosive to lead, copper, and other metals in the water system.

- http://www.madsewer.org/Programs-Initiatives/Chloride-Reduction
- https://wisaltwise.com/

Control of Nitrates

Determine the source of nitrates in the wells. From the well studies described above, are nitrates inherent in the water delivered by the aquifer? What are the possible sources of the nitrates in the watershed? Can they be prevented from entering the source water or the drinking water?

ON-GOING MONITORING FOR WATER QUALITY CONTROL

Recommendations above describe several locations of routine data gathering. Simple graphing of some water system operational data can be extremely helpful in predicting the water system's response to system operations, achieving a steady water quality, and optimizing operations.

A program of on-going data-gathering, graphing, and response to the graphs should be incorporated into operations protocols. The following is a list of helpful monitoring activities in a water system:

- Daily chemical dosing parameters should be recorded and graphed. This information is recorded for a monthly regulatory report anyway. If the data are entered into a spreadsheet daily, then they are ready for graphing. Dosing parameters for pH (caustic soda), chlorine (sodium hypochlorite), and phosphate product include pounds of product per 1000 gallons of water treated and measurement of the parameter in the water before it enters the distribution system.

- Tracking and graphing of regulatory and possibly extra measurements of the disinfection by-product groups of total trihalomethanes (TTHM) and halo-acetic acids (HAA5) at locations around the distribution system.
- Tracking and graphing of free chlorine and turbidity at Total Coliform Rule (TCR) sites. Free chlorine is already a regulatory requirement of the TCR. Turbidity measurements can be added at regular visits to TCR sites.
- Continue the collection of data at sites for iron, manganese, and free chlorine after flushing has been performed. Instead of measuring pH, measure turbidity for tracking particulates that remain entrained in the system water after water main flushing.
- Monitor iron, manganese, and certain microbiologically-related parameters at the wells routinely. Results can trigger cleaning efforts.

SUMMARY

In summary, characterization of the water system should proceed with a study of the two buildings experiencing issues, an assessment of the wells, and an assessment of the storage tanks. A February 2018 site visit is being planned by Process Research Solutions to initiate these actions and continue discussions of this report.

Plans should also be made for implementing the AECOM water main uni-directional flushing plan in the Spring of 2018.

After those actions, protocols should be established for data tracking as described above. The rest of the recommendations can also be prioritized at that point.