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DRINKING WATER QUALITY INVESTIGATION PHASE 2

For the Village of Weston Water Utility

Drinking Water Quality Investigation Phase 2

For the Village of Weston Water Utility

Report Versions

Date	Version	Comments
4/12/2018	Draft	For Village of Weston Water Utility review
4/27/2018	V1.1	Final Report
5/21/2018	V1.2	Modified references to specific buildings; added information about water main cleaning and water service line cleaning; corrected dates where year was stated incorrectly

Drinking Water Quality Investigation Phase 2

For the Village of Weston Water Utility

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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.

Drinking Water Quality Investigation Phase 2

For the Village of Weston Water Utility

Executive Summary

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 industrial heat exchangers
- 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.

An investigative report was issued on January 23, 2018. Using existing information, it was theorized that water quality issues in the Weston water system are largely a function of microbiologically influenced corrosion. In addition, there are possible influences from the presence of iron and manganese in the wells and distribution system, chloride and nitrate in the well water, adjustment of alkalinity and pH, and the addition of polyphosphate. To look closer at these theories, water sampling was performed at various sites in Weston on February 21, 2018.

Water Research Foundation Project 4586 describes the approach to these investigations using a comprehensive perspective of water quality where many chemical and microbiological factors are found to shape drinking water quality. Water quality issues are interrelated in this complex web of factors.

The results of the February sampling showed that the influence of excessive growth of microorganisms can be seen in the following ways:

- Microbiological markers for biofilm-forming microorganisms were found in the water system.
- Corrosion of metal materials of construction in Well 5 was found where lead, copper, iron, zinc, and nickel increased along with microbiological markers during stagnation of water in the well.
- Presence of soft, discolored material in piping was seen in toilet tanks. This appeared to be metals such as iron and manganese trapped in biofilm material.
- Reports of fast degradation of hot water tank sacrificial anodes and hot water odors have been made most likely as microorganisms corrode the sulfate-based anodes.
- Reports of chlorine tastes and odors have been made most likely as chlorine combines with organic compounds produced by microbiological activity.
- Pinhole leaks formed in cooling water stainless steel piping at an industry in the presence of microorganisms, probably sulfate-reducing bacteria and iron-oxidizing bacteria, and chloride.
- High biofilm formation and metals corrosion was measured in equipment at a commercial building.
- Increased microbiological activity and metals corrosion was measured in hot water systems such as domestic hot water systems, an industry's heat exchanger, and the heated water of special equipment in a commercial building.

Section 4 of this report describes more details of the multiple mechanisms found in the Weston water system that can lead to degraded water quality.

The first and critical step to improving the drinking water quality is to clean the system. Wells and piping must be cleaned of legacy accumulations of chemical scales and biofilms so that material can no longer participate in shaping the water quality. For this reason, the recommendations in Section 5 of this report focus on well maintenance and cleaning and uni-directional flushing of water mains. After the initial cleaning, protocols of routine cleaning of water system components must be given priority in water system operation. Routine monitoring of key parameters is essential for triggering the next cleaning of components in a timely manner.

Water quality issues will diminish in buildings receiving municipal water after system cleaning. However, property owners must be educated about the problem because of plumbing design and maintenance aspects that are only within their control in further diminishing the microbiological issues.

It is possible that manganese, especially, and iron concentrations still may be elevated after the cleaning protocols are carried out because of their contribution by source water. A treatment plant may be necessary in order to keep these scale-forming chemicals out of the water system. Without iron and manganese in the water, the use of polyphosphate and orthophosphate addition can be eliminated, where polyphosphate can hold lead and copper and elevate their concentrations in the water. The phosphate product also fulfills the necessary nutrient demand for microbiological growth. The iron and manganese scales can also hold other metals, such as lead and copper, and transport them around the water system. Therefore, there are many advantages to preventing iron and manganese from entering the distribution system.

There are further recommendations in Section 5 of this report for control of disinfection dosing, formation of disinfection by-products, pH, alkalinity, chloride, and nitrates. Control of these chemicals along with system cleaning comprise a recommended program for improvement of drinking water quality in Weston.

Drinking Water Quality Investigation Phase 2

For the Village of Weston Water Utility

List of Abbreviations

Abbreviation	Description
ATP	Adenosine tri-phosphate, a chemical found in living organisms. Estimate microbiological population in water using 1000 water bacteria per pg ATP
BCI	Biofilm corrosion index, developed by a microbiological laboratory to show the potential that biofilms are forming and causing metals corrosion
BDL	Below detection limit
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium carbonate
CB	Commercial Building
CCPP	Calcium carbonate precipitation potential
DP EEM	Decay products identified by the excitation-emission matrix analysis; organic carbon compounds in water from decaying materials and dead microorganisms
EEM	Excitation-emission matrix analysis, where wavelengths of light are bounced through a water sample and specific organic carbon compounds fluoresce with different wavelengths as a measure of various types of organic carbon compounds present
IB	Industrial Building
LI	Langelier Index
MBP EEM	Metabolic by-products EEM; organic carbon compounds in water from living microorganisms
ME/mL	Microbial equivalents per mL; this unit is an estimate the population of microorganisms in the water based on measuring the concentration of ATP and
mg/L	Miligrams per liter
MIC	Microbiologically influenced corrosion
ND	Not detected
ORP	Oxidation-reduction potential
P	Phosphorus
pg/mL	Picograms per milliliter

PO4	orthophosphate
Total EEM	Sum of DP EEM and MBP EEM
UDF	Uni-directional flushing
µg/L	Micrograms per liter

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.
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- Chlorine tastes and odors.
- Corrosion of industrial heat exchangers
- 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 was 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 is in follow-up to an investigative report dated January 23, 2018. In that initial phase of the investigation, existing data were used to identify critical aspects of the water quality issues and propose a sampling plan to gather more information. The sampling was performed on February 21, 2018. This report summarizes results and states conclusions and recommendations for water quality improvement.

Section 2: Project Approach

A COMPREHENSIVE PERSPECTIVE OF 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 (http://www.waterrf.org/Pages/Projects.aspx?PID=4586)
- CRC Press book on Monitoring (2nd edition) – purchase from crcpress.com (https://www.crcpress.com/Water-Distribution-System-Monitoring-A-Practical-Approach-for-Evaluating/Cantor/p/book/9781138064034)

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.

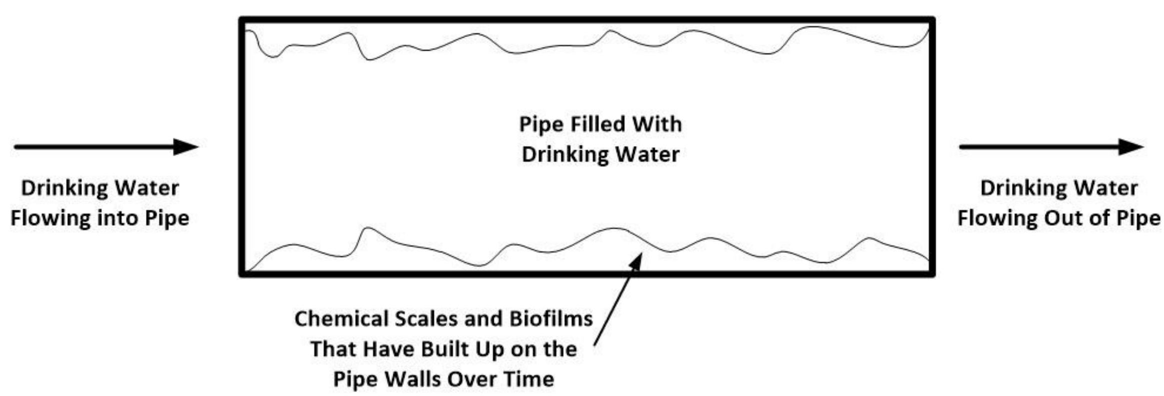

Figure 2.1 Typical Drinking Water Pipe

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.

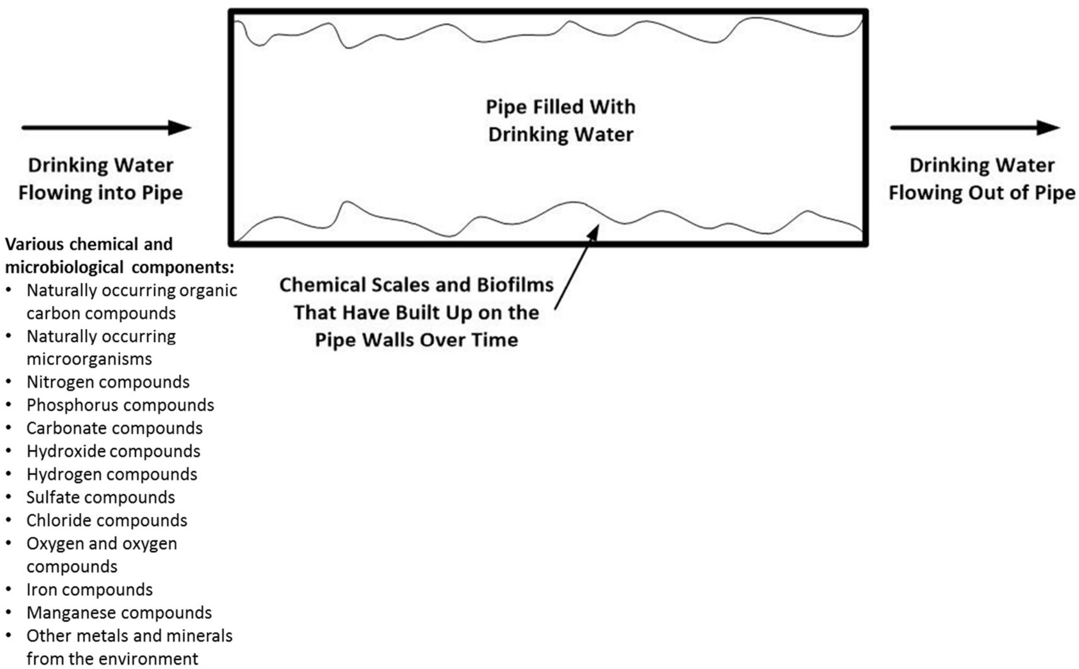

Figure 2.2 Typical Composition of Drinking Water Flowing into a Pipe

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

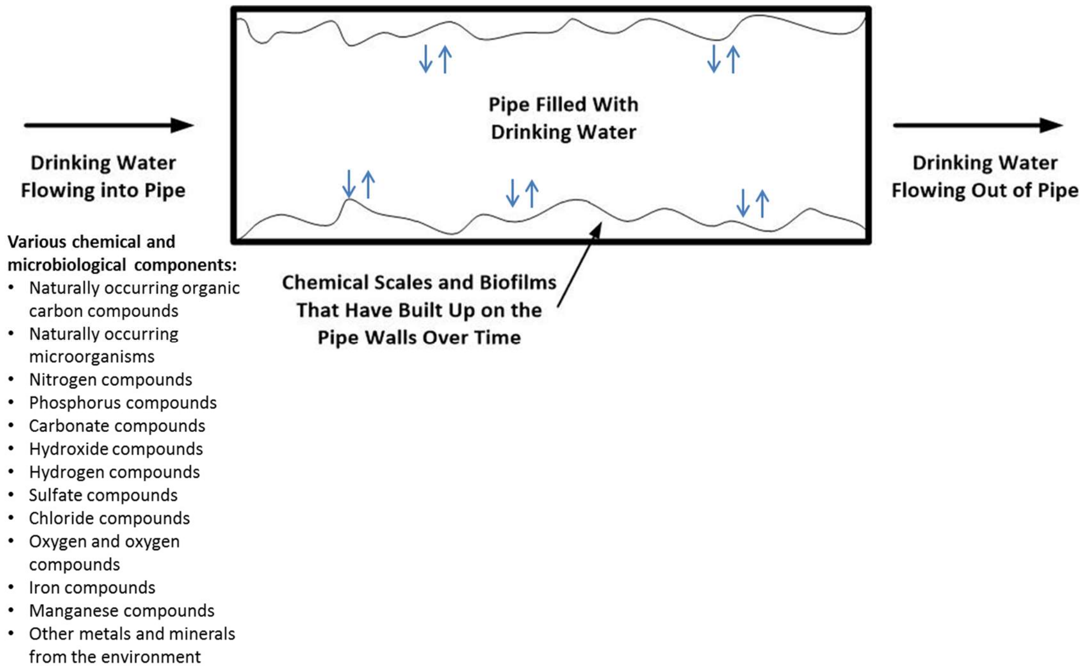

Figure 2.3 Typical Interactions between Pipe Walls and Drinking Water

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.

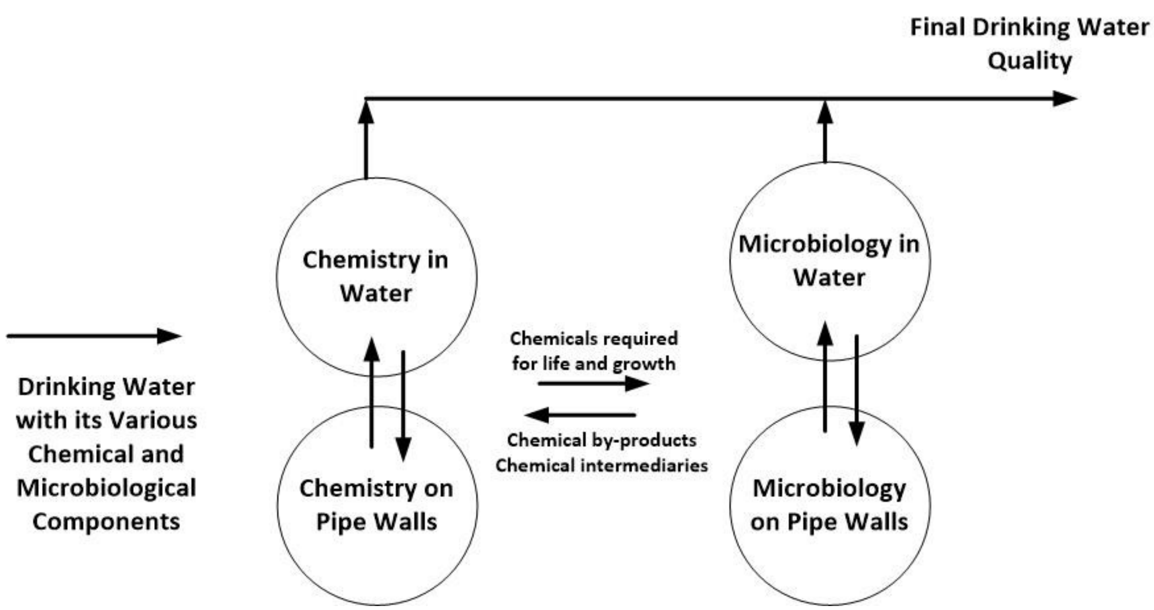

Figure 2.4 The Shaping of Water Quality

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.

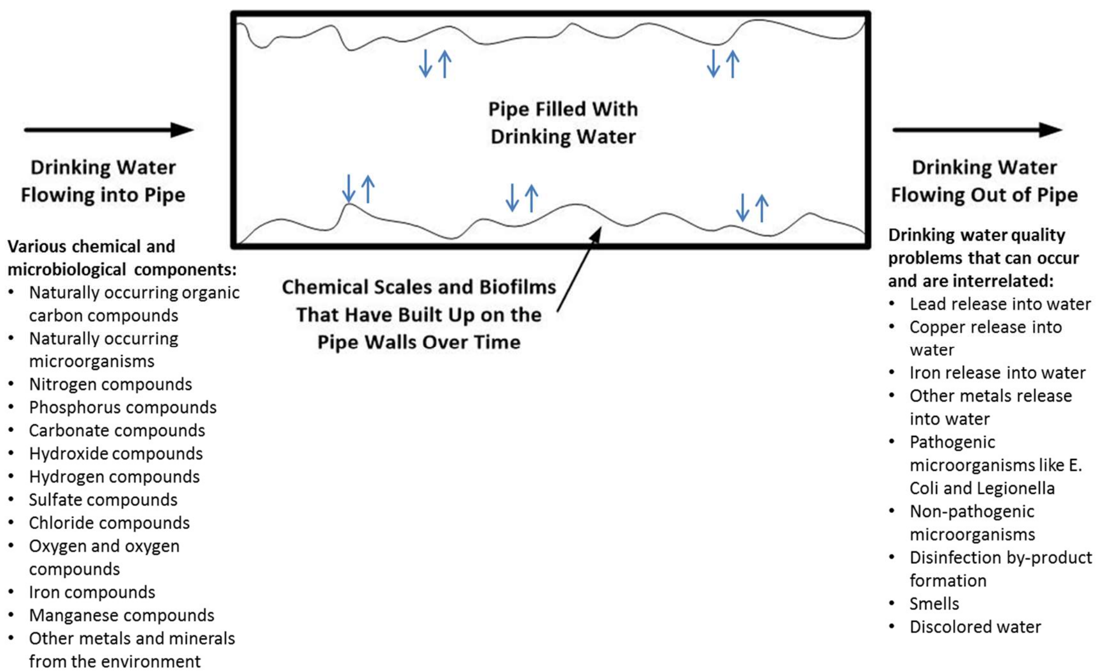

Figure 2.5 Interrelated Distribution System Drinking Water Quality Problems

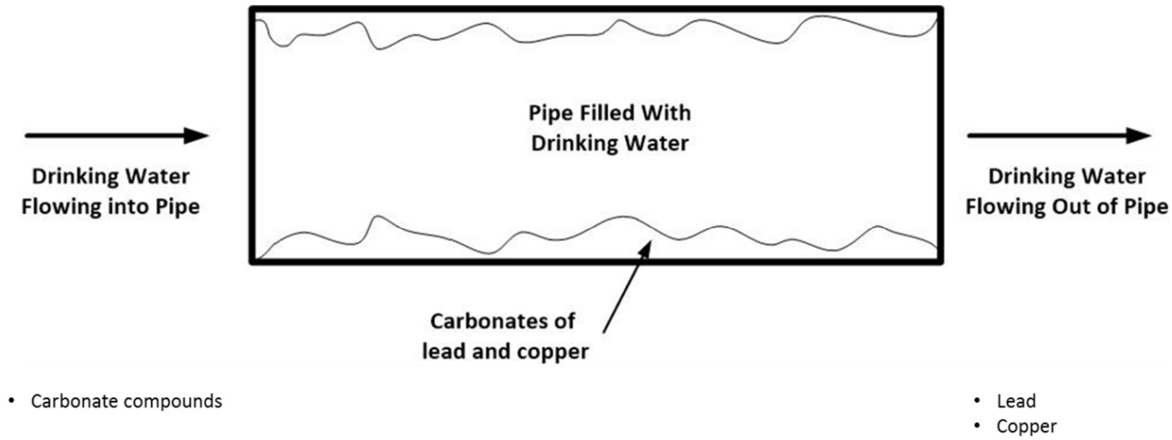

Figure 2.6 Regulatory Perspective of Lead and Copper Release

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.

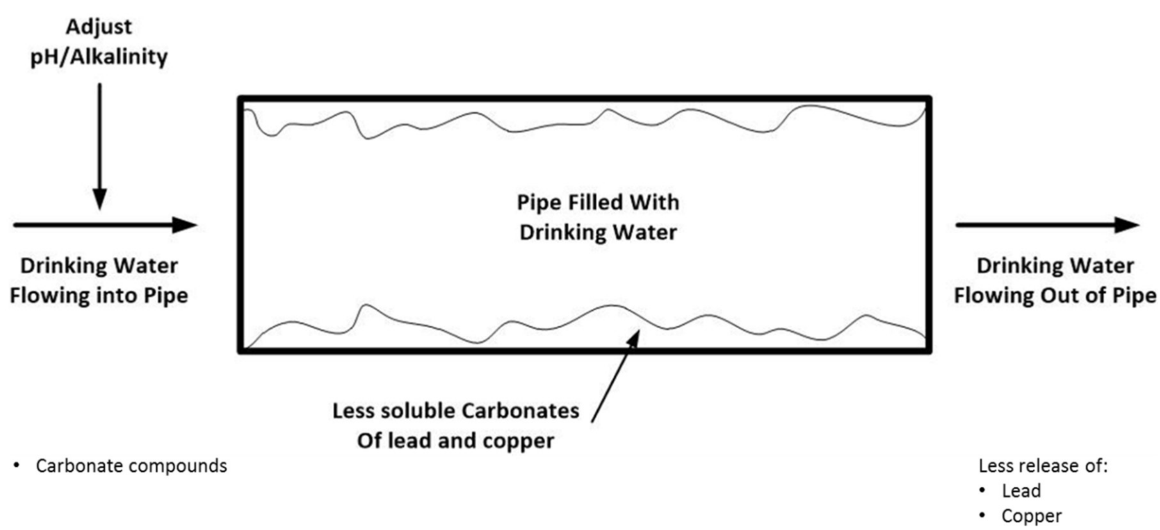

Figure 2.7 Regulatory Solution to Lowering Lead and Copper Release (Option 1)

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.

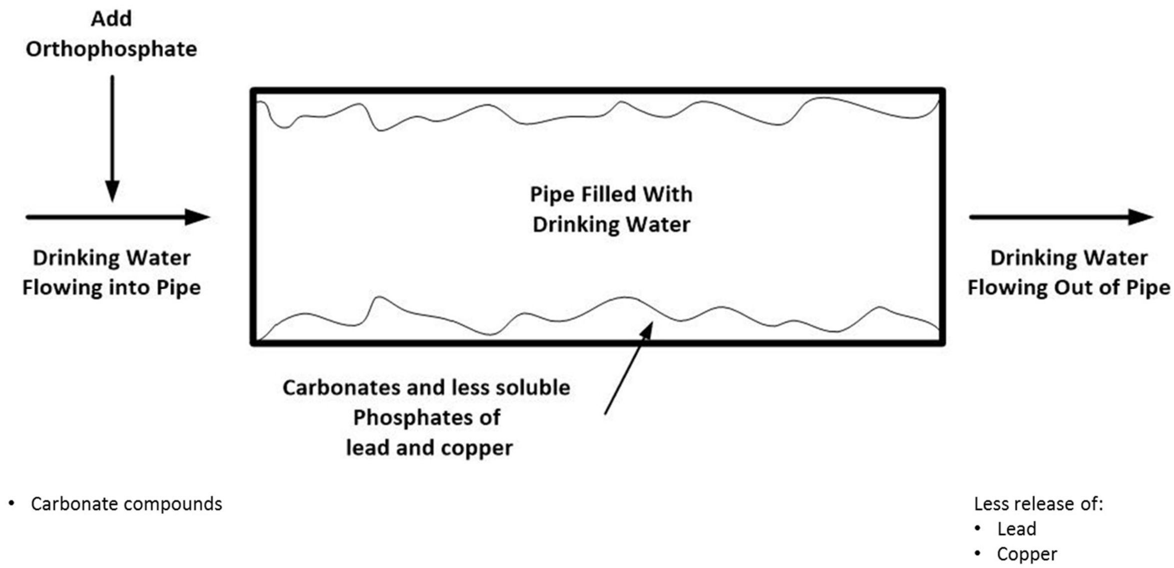

Figure 2.8 Regulatory Solution to Lowering Lead and Copper Release (Option 2)

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.

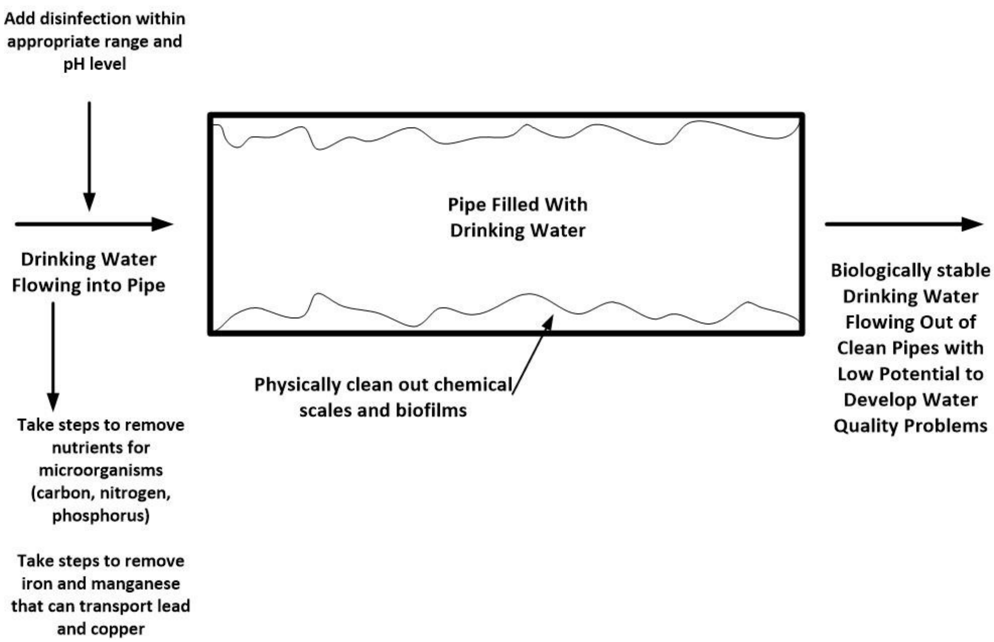

Figure 2.9 Comprehensive Solution to Lead and Copper Release and Interrelated Issues

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.

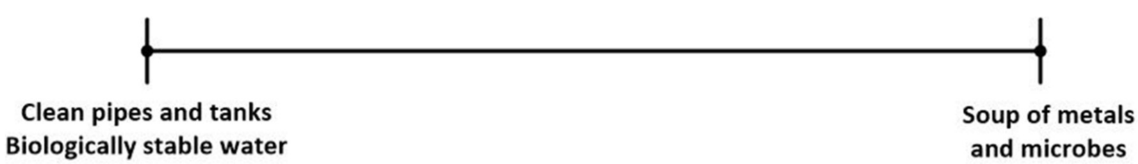

Figure 2.10 Water Quality Continuum

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.

INVESTIGATIVE SAMPLING PLAN

A day of water sampling was planned for February 21, 2018 in the Weston water system. The sampling strategy involved capturing the characteristics of flowing water and comparing them to the characteristics of water that had been stagnating. Stagnation allows for the occurrence of chemical reactions and microbiological interactions with by-products that can be measured.

The sampling sites included:

- A commercial building (Commercial Building 1) where there had been complaints of discolored water
- A second commercial building (Commercial Building 2) where there had been complaints of discolored water
- Three water towers
- Well 5
- A third commercial building (Commercial Building 3) where there had been complaints of discolored water
- A residence with reports of short-lived hot water tanks
- An industry (Industrial Building) with an epidemic of pinhole leaks in stainless steel heat exchanger piping

Water quality parameters were selected for their possible participation in the three categories of factors that shape water quality as described in the comprehensive perspective. The water quality parameters studied were:

- Factors that affect uniform corrosion of metals
    - pH
    - Total alkalinity

    - Temperature
    - Conductivity
    - Oxidation-reduction potential (ORP)
    - Sulfate
    - Chloride
    - Nitrate
- Factors that affect microbiologically influenced corrosion and the biostability of water
    - pH
    - Total alkalinity
    - Temperature
    - ORP
    - Sulfate
    - Nitrate
    - Ammonia
    - Total phosphorus
    - Dissolved organic carbon
    - Microbiological population
    - Potential for biofilm formation
- Factors that affect the formation and dissolution of chemical scales throughout the distribution system
    - Conductivity
    - Metals (scan of 18 metals)

Section 3: February 2018 Sampling Results

The results of sampling are listed in this section and explained in this section and in Section 4.

In Table 3.1, results of metals release at Well 5 are listed. Before sampling, the well was not used for at least 24 hours in order to allow water to stagnate in the well. The well pump was started and Sample #1 was taken as soon as possible. Sample #2 was taken just after that. Sample #3 was taken 15 minutes after the well pump was started. The rest of the samples were: Sample #4 at 30 minutes, Sample #5 at 45 minutes, Sample #6 at 60 minutes after the well pump was started.

Metals that were studied were:

- Metals from piping and tank corrosion
- Metals from either corrosion or from the source water
- Other minerals in the source water

There were also parameters measured that are associated with uniform corrosion and with biostability of water.

From Table 3.1, it is seen that copper corrosion is not an issue in the well but some component with lead in the alloy was contributing elevated concentrations of lead soon after the well pump started up. After 15 minutes, the lead concentration dropped but lead still was present. This is most likely not from the source water and local geology but from corrosion of well casing components. Zinc and nickel were also being added into the water by means of corrosion of well casing components during the sampling.

Iron and manganese can be a result of either natural source water metals or from corrosion of piping and tanks. It is seen that, when the well pump first started up, the initial plug of water was adjacent to a corroding iron component. Manganese, at a constant level throughout the pumping, appeared to be more indicative of the characteristics of the water shaped by the aquifer.

There are other minerals that are characteristic of the water from the aquifer that remained steady over the hour of pumping – calcium, magnesium, barium, potassium, sodium, and strontium.

The alkalinity was higher in the initial plug of water delivered by the well pump than the rest of the water pumped. Alkalinity is typically associated with uniform corrosion. However, localized increases in alkalinity can be associated with the activity of autotrophic bacteria which can utilize carbon dioxide in the water for nutrition and increase the inorganic and organic carbon in the location.

Table 3.1 Metals Release at Well 5

Parameters	Units	Successive stagnant samples at Well 5						Limit of Detection
		#1	#2	#3	#4	#5	#6	
Metals from piping and tank corrosion								
Copper	µg/L	2.7	7.2	9	8.8	8.1	6.8	1
Lead	µg/L	0.29	28	18	6.8	7.2	9.4	0.1
Aluminum	mg/L	ND	ND	ND	ND	ND	ND	0.005
Zinc	µg/L	ND	25	37	50	28	38	5
Tin	µg/L	ND	ND	ND	ND	ND	ND	0.1
Nickel	µg/L	ND	0.98	3	2.5	2	1.7	0.5
Chromium	µg/L	ND	ND	ND	ND	ND	ND	0.5
Cadmium	µg/L	ND	ND	ND	ND	ND	ND	0.1
Cobalt	µg/L	ND	ND	ND	ND	ND	ND	0.5
Metals either from corrosion or from source water								
Iron	µg/L	210	41	83	35	33	34	18
Manganese	µg/L	160	110	110	110	110	110	1
Minerals in source water								
Calcium	mg/L	37	36	35	35	35	34	0.15
Magnesium	mg/L	15	15	14	14	14	14	0.15
Arsenic	µg/L	ND	ND	ND	ND	ND	ND	0.5
Barium	µg/L	61	67	66	65	66	65	0.1
Potassium	mg/L	1.8	1.9	1.8	1.8	1.8	1.8	0.15
Sodium	mg/L	97	110	110	110	110	110	0.15
Strontium	µg/L	150	160	150	150	150	150	0.25
Parameters associated with uniform corrosion of metals								
Total Alkalinity	mg/L as $CaCO_3$	110		57	56	57	57	2
Chloride	mg/L						230	
Sulfate	mg/L						17	
Parameters associated with biostability of water								
Dissolved Organic Carbon	mg/L	0.71		0.68	0.62	0.69	0.61	0.50
Ammonia Nitrogen	mg/L	0.072		0.069	0.069	0.11	0.093	0.027
Nitrate + Nitrite Nitrogen	mg/L	3.2		3.3	3.5	3.5	3.5	0.13
Total Phosphorus	mg/L as P	ND		ND	ND	ND	ND	0.022

ND=Not Detected

Also seen in Table 3.1 was elevated chloride from the aquifer. These relatively shallow wells can be a conduit for road salt that has dissolved from the roads and been released to the environment. The sodium and chloride can find their way into drinking water sources and into the water distribution systems, increasing the potential for metals corrosion.

Microbiological nutrients of organic carbon, nitrogen compounds, and phosphorus compounds can be measured. The initial plug of water delivered by the well pump had slightly higher organic carbon concentration, which might indicate that excessive growth of microorganisms was occurring in the water as it stagnated in the well, especially near the suction of the well pump. This corresponded to a suspicious increase of alkalinity at that location. There was a source of ammonia at the 45 and 60-minute mark of well pumping. Phosphorus, before the addition of phosphate for sequestration, was below detection level.

In Table 3.2, copper in Commercial Building 2's flowing and stagnating water was low. Lead was not an issue in the building, but a low concentration did register in the stagnating water of some special equipment. Zinc and nickel were also seen corroding at a low degree in that equipment. At the sink in Commercial Building 2 (Table 3.2), iron and manganese were present at levels where aesthetic issues of discolored water can occur. The metals could be from well water or from corrosion occurring in water mains or service line and carried in by the system water. The lack of iron and manganese in the special equipment water may actual mean that the metals had precipitated out or were bound by organic material on the tubing walls. In Table 3.3 at the laundry sink of a residence where water had been sitting stagnant, copper was higher than seen in Commercial Building 2 and in Well 5. Copper, at 260 µg/L, is not considered elevated and is far away from the health maximum of 1300 µg/L. However, relative to concentrations found below 25 µg/L elsewhere, copper was corroding in the residence. Aluminum, zinc, tin, and nickel were also found as corrosion by-products in the water.

Results from an industry in Table 3.4 show more metals release in the domestic hot water system than in the cooling water of the heat exchanger. However, the stainless-steel piping of the heat exchanger had been experiencing pinhole leaks, which is a more localized form of metals corrosion.

Microbiological parameters are shown in Table 3.5. ATP is an abbreviation for adenosine triphosphate, the energy molecule of living cells. For convenience, it is estimated that an "average" bacteria in water has 1000 picograms per milliliter of ATP per organism. Using this, an estimated population of bacteria can be stated as microbial equivalents (ME) per mL. Using regulatory standards, 500 microorganisms (alternatively, microbial equivalents per mL) or below is desired in the water.

Table 3.2 Metals Release at Commercial Building 2

Parameters	Units	Commercial Building 2			Limit of Detection
		Sink Cold Water	Sink Cold Water	Special Equipment	
		Flowing	Stagnating	Stagnating	
Metals from piping and tank corrosion					
Copper	µg/L	13	25	9.4	1
Lead	µg/L	ND	ND	1.6	0.1
Aluminum	mg/L	ND	ND	ND	0.005
Zinc	µg/L	ND	100	200	5
Tin	µg/L	ND	ND	ND	0.1
Nickel	µg/L	ND	4.1	1.7	0.5
Chromium	µg/L	ND	ND	ND	0.5
Cadmium	µg/L	ND	ND	ND	0.1
Cobalt	µg/L	ND	ND	ND	0.5
Metals either from corrosion or from source water					
Iron	µg/L	330	290	ND	18
Manganese	µg/L	26	9.7	1.5	1
Minerals in source water					
Calcium	mg/L	23	23	31	0.15
Magnesium	mg/L	7.9	8.1	5.0	0.15
Arsenic	µg/L	ND	ND	ND	0.5
Barium	µg/L	58	59	1.4	0.1
Potassium	mg/L	3	3	4.7	0.15
Sodium	mg/L	67	68	100	0.15
Strontium	µg/L	130	140	120	0.25
Parameters associated with uniform corrosion of metals					
Total Alkalinity	mg/L as $CaCO_3$	40			2
Chloride	mg/L	130			
Sulfate	mg/L	12			
Parameters associated with biostability of water					
Dissolved Organic Carbon	mg/L	0.90			0.5
Ammonia Nitrogen	mg/L	0.07			0.027
Nitrate + Nitrite Nitrogen	mg/L	2.7			0.13
Total Phosphorus	mg/L as P	0.87			0.022

Table 3.3 Metals Release at a Residence

Parameters	Units	Residence		Limit of Detection
		Cold Water Laundry Sink	Hot Water Laundry Sink	
		Stagnating	Stagnating	
Metals from piping and tank corrosion				
Copper	µg/L	260	140	1
Lead	µg/L	0.48	0.15	0.1
Aluminum	mg/L	ND	0.023	0.005
Zinc	µg/L	240	21	5
Tin	µg/L	0.16	ND	0.1
Nickel	µg/L	3.4	0.61	0.5
Chromium	µg/L	ND	ND	0.5
Cadmium	µg/L	ND	ND	0.1
Cobalt	µg/L	ND	ND	0.5
Metals either from corrosion or from source water				
Iron	µg/L	70	76	0.018
Manganese	µg/L	13	8.7	1
Minerals in source water				
Calcium	mg/L	30	29	0.15
Magnesium	mg/L	11	10	0.15
Arsenic	µg/L	ND	ND	0.5
Barium	µg/L	77	73	0.1
Potassium	mg/L	2.8	2.7	0.15
Sodium	mg/L	99	91	0.15
Strontium	µg/L	160	150	0.25

Table 3.4 Metals Release at an Industry

Parameters	Units	Industrial Building			Limit of Detection
		Heat Exchanger Water	Building Entry Water	Domestic Hot Water	
		Stagnating	Flowing	Stagnating	
Metals from piping and tank corrosion					
Copper	µg/L	ND	3.4	18	1
Lead	µg/L	ND	0.76	4.1	0.1
Aluminum	mg/L	ND	ND	ND	0.005
Zinc	µg/L	ND	19	330	5
Tin	µg/L	ND	ND	0.1	0.1
Nickel	µg/L	4.2	ND	68	0.5
Chromium	µg/L	12	ND	110	0.5
Cadmium	µg/L	ND	ND	ND	0.1
Cobalt	µg/L	ND	ND	ND	0.5
Metals either from corrosion or from source water					
Iron	µg/L	30	ND	240	18
Manganese	µg/L	15	230	79	1
Minerals in source water					
Calcium	mg/L	35	35	35	0.15
Magnesium	mg/L	12	12	12	0.15
Arsenic	µg/L	ND	ND	ND	0.5
Barium	µg/L	30	34	27	0.1
Potassium	mg/L	1.6	1.7	1.6	0.15
Sodium	mg/L	98	94	98	0.15
Strontium	µg/L	140	140	140	0.25
Parameters associated with uniform corrosion of metals					
Total Alkalinity	mg/L as $CaCO_3$	77	78		2
Chloride	mg/L	180	180		
Sulfate	mg/L	15	15		
Parameters associated with biostability of water					
Dissolved Organic Carbon	mg/L	0.74	0.76		0.5
Ammonia Nitrogen	mg/L	0.081	0.087		0.027
Nitrate + Nitrite Nitrogen	mg/L	3.1	2.5		0.13
Total Phosphorus	mg/L as P	0.60	0.62		0.022

Table 3.5 Microbiological Activity at All Sites

Site	ATP ME/mL	MBP EEM	DP EEM	Total EEM	BCI
Well 5 Successive Samples					
#1	4,850	88,614	230,853	319,467	0.67
#2	940	90,329	228,079	318,408	0.69
#3	417	92,250	228,731	320,981	0.72
#4	251	90,682	225,717	316,399	0.71
#5	276	91,085	228,125	319,210	0.71
#6	275	91,732	230,741	322,473	0.71
Tower: Business Park	BDL	72,073	162,783	234,856	0.66
Tower: East Everest	243	81,896	185,834	267,730	0.77
Tower: Treatment Plant	104	80,898	205,109	286,007	0.68
CB 1 Cold Water Stagnating	292	82,983	194,621	277,604	0.72
CB 1 Hot Water Stagnating	453	166,958	234,013	400,971	1.83
CB 2 Cold Water Flowing	BDL	73,852	173,352	247,205	0.68
CB 2 Cold Water Stagnating	184	72,689	163,186	235,875	0.68
CB 2 Sink Hot Water Stagnating	BDL	74,316	144,839	219,155	0.75
CB 2 Special Equipment Stagnating	327	955,511	460,683	1,416,195	13.18
CB 2 Toilet Tank	1,520	70,161	172,536	242,697	0.60
IB Entry Point	BDL	69,708	167,848	237,555	0.60
IB Heat Exchanger	144	73,191	172,096	245,287	0.62
IB Heat Exchanger, 2nd sample	BDL	82,956	168,135	251,091	0.80
IB Domestic Hot Water	5,593	91,307	220,114	311,421	0.78
CB 3 Softened Cold Water Sink	BDL	93,405	192,885	286,289	0.91
CB 3 Hot Water Sink	194	74,266	148,822	223,089	0.71
Residence Laundry Sink Cold Water	80	84,844	184,914	269,758	0.80
Residence Laundry Sink Hot Water	BDL	106,502	155,184	261,686	1.31
Residence Toilet	575	91,488	198,731	290,219	0.86

BDL= Below Detection Limit
CB = Commercial Building
IB = Industrial Building

In Table 3.5, EEM is an abbreviation for excitation-emission matrix. This refers to an analytical method for differentiating the types of organic carbon material present in the water. Certain types of organic carbon compounds are present as metabolic by-products of living microorganisms (MBP EEM). Other types of organic carbon compounds represent decay products (DP EEM) from the source water or from biofilm material created by microorganisms. The analytical laboratory reports that a Total EEM (MBP + DP EEM) greater than 100,000 units indicates a greater potential for biofilm formation and water quality issues that they can cause. BCI is a "biofilm corrosivity index" developed by the laboratory; as the BCI increases, the potential for metals corrosion increases.

From Table 3.5, it is seen that there can be a low population of microorganisms living in the water (ATP) but a great potential that there are biofilms forming and protecting the microbiological populations (Total EEM). An accompanying elevated BCI indicates that the metals corrosion potential is high. In Well 5, the first plug of water pumped when the pump started had a higher population of microorganisms living in the water than the rest of the stagnating well. But, there was about the same potential for biofilm formation and metals corrosion throughout the well. The tower water appeared to be similar in microbiological make-up as Well 5. At Commercial Building 1 and at the residence, the hot water had a greater potential for microbiologically influenced corrosion of metals occurring than the cold water. The same was true at the Commercial Building 2. However, the special equipment was undergoing an extreme tendency for biofilm formation and metals corrosion. At the Commercial Building 3, the softened cold water had a higher potential for biofilm formation and metals corrosion. Softener media is prone to biofilm formation because of high surface area for attachment and slow-moving water. The heated water at the Industrial Building in the domestic hot water system and as cooling water in the heat exchanger also had a greater biofilm and corrosion potential than the colder water.

Tables 3.6 and 3.7 show parameters measured both in the field and in the laboratory. The higher oxidation-reduction potential (ORP) is an environment in the water where it is difficult for microorganisms to live; however, they can still thrive protected by biofilms. The pH represents the acidity of the water; changes up or down in pH can be caused by various types of microorganisms and their metabolic pathways. Conductivity is a measure of dissolved solids in the water. Minerals in the water add to a higher conductivity, but metals corrosion also increases the conductivity. Field test results are more accurate because components in the water have volatilized and the water characteristics slightly changed by the time the sample arrives at the laboratory.

Disinfection is shown in Table 3.8. The disinfection concentration had been boosted to around 1 mg/L at the time of sampling which is a substantial dose for drinking water. Disinfection dissipated in hot water.

Table 3.6 Parameters Related to Microbiological Activity at All Sites

	Lab ORP	Lab pH	Lab Conductivity
Site	**mV**	**SU**	**uS/cm**
Well 5 Successive Samples			
#1	423	7.06	1007
#2	417	7.00	997
#3	401	7.13	977
#4	395	7.01	980
#5	379	7.15	980
#6	381	7.09	969
Tower: Business Park	695	7.70	629
Tower: East Everest	691	7.71	623
Tower: Treatment Plant	591	7.43	620
CB 1 Cold Water Stagnating	610	7.50	711
CB 1 Hot Water Stagnating	518	7.54	584
CB 2 Cold Water Flowing	721	7.52	623
CB 2 Cold Water Stagnating	712	7.49	624
CB 2 Sink Hot Water Stagnating	657	7.55	628
CB 2 Special Equipment Stagnating	370	7.49	794
CB 2 Toilet Tank	681	7.65	624
IB Entry Point	552	7.50	857
IB Heat Exchanger	616	7.79	856
IB Heat Exchanger, 2^{nd} sample	672	7.81	856
IB Domestic Hot Water	369	7.52	860
CB 3 Softened Cold Water Sink	724	7.50	1052
CB 3 Hot Water Sink	669	7.47	1042
Residence Laundry Sink Cold Water	706	7.52	904
Residence Laundry Sink Hot Water	583	7.47	787
Residence Toilet	684	7.44	666

CB = Commercial Building
IB = Industrial Building

Table 3.7 Field Tests at All Sites

Sampling Site	Flow	pH	Conductivity	ORP	Temperature
		SU	uS/cm	mV	deg C
Well 5 Successive Samples					
#1	Stagnating	6.70	1021	322	14.9
#2	Stagnating	6.45	988	300	15.7
#3	Stagnating	6.48	982	290	15.8
#4	Stagnating	6.53	981	307	15.1
#5	Stagnating	6.48	977	267	14.3
#6	Stagnating	6.55	971	273	13.3
Towers					
Business Park	Early morning	7.51	648	724	6.30
East Everest	Early morning	7.26	643	707	7.30
Treatment Plant	Early morning after aeration but before re-chlorination	7.13	637	668	11.1
CB 1					
Sink Cold Water	Flowing	7.34	664	715	13.6
Shower Hot Water	Flowing	7.32	676	286	47.1
Sink Cold Water	Stagnating	6.93	722	672	20.7
Shower Hot Water	Stagnating	7.22	688	514	39.4
CB 2					
Sink Cold Water	Flowing	7.36	628	716	10.0
Sink Cold Water	Stagnating	7.26	642	684	19.8
IB					
Entry Point Cold Water	Flowing	7.08	872	696	13.4
Heat Exchanger	Stagnating	6.89	886	583	33.3

CB = Commercial Building
IB = Industrial Building

Table 3.8 More Field Tests at All Sites

Sampling Site	Flow	Free Chlorine	Total Chlorine	Field Hardness
		mg/L	mg/L	mg/L as $CaCO_3$
Well 5 Successive Samples				
#1	Stagnating			
#2	Stagnating			
#3	Stagnating			
#4	Stagnating			
#5	Stagnating			
#6	Stagnating			
Towers				
Business Park	Early morning	0.89		
East Everest	Early morning			
Treatment Plant	Early morning after aeration but before re-chlorination	0.44		
CB 1				
Sink Cold Water	Flowing	0.92	1.03	120
Shower Hot Water	Flowing	0.02	0.12	25
Sink Cold Water	Stagnating			
Shower Hot Water	Stagnating			
CB 2				
Sink Cold Water	Flowing	1.08		120
Sink Cold Water	Stagnating			
IB				
Entry Point Cold Water	Flowing	1.00		
Heat Exchanger	Stagnating	0.47		

CB = Commercial Building
IB = Industrial Building

Section 4: Conclusions

Microbiologically influenced corrosion (MIC). The water quality issues that are occurring in the Weston water system are significantly microbiological in nature. Table 3.5 shows that there is a tendency for microorganisms to survive in substantial biofilms on pipe walls in the water system with the potential for metals corrosion.

Metals corrosion can occur by several different metabolic pathways. The biofilms that are excreted by microorganisms are acidic and the localized acidity on the metal surfaces can corrode the metal. Microorganisms can produce acidic waste products released to the water, such as hydrogen sulfide, that lowers the pH of the water and corrodes metal. This can be either a localized issue or a system-wide issue. Another system-wide issue can be that waste products, such as nitrates and acetates (a type of organic carbon) can be produced that are released to the water and aid in perpetuating uniform corrosion of metals. There are also microorganisms that can oxidize metals directly by utilizing electrons from the metal.

MIC of stainless steel piping. Another pathway is possibly on display at the Industrial Building where the stainless-steel piping is undergoing pinhole leak corrosion. In this case, there is possibly a synergistic combination of sulfate-reducing bacteria, iron-oxidizing bacteria, and chloride that has been reported in the technical literature as an environment for increased corrosion of stainless steel piping. There is also a possibility that carbon in the steel can be used as a carbon source, but research is unclear about this possibility. Nevertheless, Table 3.5 indicates that a form of microbiologically influenced corrosion is occurring in the Industrial Building's heat exchanger and a different form of it occurring in the domestic hot water system, different because of the difference in piping material.

MIC in premise plumbing. Weston's microbiological problem was magnified in hot water systems and in softened water (Table 3.5). Microbiological growth in hot water systems is favored by elevated temperature and by longer residence time in the system because of the hot water tank. Microorganisms have been observed to corrode the sacrificial anodes of hot water tanks very quickly. This has been documented in a summary of Process Research Solutions' premise plumbing investigations in the booklet, "What's Bugging Your Pipes?" (https://www.amazon.com/Whats-Bugging-Your-Pipes-Microorganisms-ebook/dp/B00FPTP1P0/ref=sr_1_1_twi_kin_1?ie=UTF8&qid=1523457139&sr=8-1&keywords=What%27s+Bugging+Your+Pipes).

This leads to rotten egg odors and elevated metals in the water and structural failure of the hot water tank. The booklet also summarizes findings that water softeners can become incubators for excessive microbiological growth. The softener media is a place where high surface area and slow-moving water provides an environment for biofilm formation.

MIC in wells. The microbiological problem for the water system begins with the wells. In general, wells in all water systems are not cleaned and disinfected often enough which allows microbiological activity to proceed in the well's casing and borehole. The microorganisms are from the soil and air but can thrive in the well's environment to grow excessively. The initial water introduced into the drinking water system when a well pump starts up has a higher quantity of microorganisms, nutrients, and biofilm materials than during the pumping cycle because of the previous stagnation period where those materials were transferred to the water. This means that every time a well stagnates and then is started up, the water system is inoculated with microbial activity components. There can also be a zone of water within the well that is not pumped out because of particular configurations of the pump in the well. Such stagnant zones encourage excessive microbiological activity and the by-products can migrate into the pumped water.

Iron and manganese. Iron enters the drinking water from two sources. One source of iron is from the geological contributions in the aquifer. In Well 5, the background aquifer iron concentration was 35 µg/L (Table 3.1). However, the iron was 210 µg/L within the well from corroded iron components. At the Commercial Building 2, iron was measured flowing into the building at 330 µg/L (Table 3.2). That iron was most likely from corroded components in the wells and in the distribution system piping.

Manganese, however, appeared to be present in Well 5 from the geological contribution in the aquifer (Table 3.1). The concentration throughout the pumping experiment was steady at 110 µg/L. This level is above the voluntary aesthetic regulation of 50 µg/L.

Each well has its own level of iron and manganese contributed by the aquifer and mostly iron contributed by corroding materials in the well. Each building has its own concentrations of iron and manganese entering and remaining in the plumbing systems representing a combination of specific wells in use at that location and time, precipitation of particulate metals, entrainment of particulate metals, and dissolution of metals. It can be assumed that there exists accumulations of iron and manganese scales in the water mains and in premise plumbing systems.

Deposits in premise plumbing and distribution system piping. Soft, reddish-brown material found in premise plumbing systems, such as in the toilet tanks of Commercial

Building 2 and the residence, is a combination of biofilm material that has entrapped iron and manganese. This is an example of the accumulations that can most likely be found on pipe walls throughout the water system. A similar phenomenon was observed in Water Research Foundation Project 4586 (referenced in Section 2) for Water System D, which was a water system in the vicinity of Weston. The metal plates exposed to Water System D water in the test chambers of a special monitoring station were examined by scanning electron microscopy and X-ray diffraction to define this film as an amorphous configuration of carbon, iron, manganese, and phosphorus. Microbiological examination of the plates confirmed a high microbiological population attached to the metal plate surfaces in comparison to a low microbiological population in the water.

Chemical reactions with microbiologically-produced chemicals – from carcinogens to odors. Chemical compounds produced by microorganisms can combine with other chemicals in the water system to cause other water quality issues. Organic carbon compounds can combine with chlorine to form disinfection by-products. It was noted in the 1/23/2018 report that disinfection by-products were slowly increasing over time in the Weston water system. Nitrogen-based compounds, such as ammonia, can combine with chlorine to form chloramines, which give off a “chlorine” odor in the water.

Nutrient balance. Microorganisms need nutrients of carbon, nitrogen, and phosphorus to thrive. These nutrients are listed in Tables 3.1 to 3.4. When the concentrations of the nutrients are divided by their molecular weight, moles of each nutrient are calculated. The ratio of moles of each nutrient to each other reveals whether or not a nutrient is available in sufficient quantity for microbiological nutrition. In this way, it is seen that there are ample concentrations of nitrogen and phosphorus in the water, but not enough organic carbon to allow microorganisms to thrive in the water. This explains the relatively low populations of microorganisms measured in the water as shown in Table 3.5. But, the lack of organic carbon allows for the dominance of autotrophic bacteria, where inorganic carbon can be utilized as a nutrient. The inorganic carbon is available as carbon dioxide and as carbonates in the water. When there are also energy sources, such as ammonia, iron, sulfur, or manganese, autotrophic bacteria can gain access to the inorganic carbon as a nutrient. The water in Weston supplies the iron, sulfur and manganese as energy sources. This would explain the tendency in the water to form biofilms and to observe corrosion, especially, of the Industrial Building’s stainless-steel piping. This would also explain the corrosion of the sulfate-based sacrificial anodes in hot water tanks. In other words, this water favors the growth of autotrophic bacteria which are protected by their biofilms. In locations where conditions are even more favorable to their growth, microorganisms can cause increased and specialized metals corrosion, such as in the Industrial Building's heat exchanger piping and in hot water tanks.

Chloride. The presence of chloride in the source water is most likely from road salt. The increase in chloride and sodium in well water and surface water is an emerging threat to drinking water sources. Chloride encourages the uniform corrosion of metals by forming highly soluble compounds with metals released in the uniform corrosion process. No protective barriers are formed in the presence of chloride and metal continues to corrode and remain dissolved in the water.

Nitrates. Nitrates that come in from the source water also can hold importance in both promoting chemical corrosion of metal and microbiologically influenced corrosion. Nitrates form soluble compounds with metal ions released by the uniform corrosion process as does chloride. And, nitrogen is a key nutrient for sustaining microbiological growth and subsequent microbiologically influenced corrosion.

Copper. Copper concentration in water is not considered to be a water quality issue in Weston because levels are found well below the maximum contaminant level health goal of 1300 µg/L. However, it was seen in the sampling results that copper release is relative and elevation in copper concentration can signify microbiologically influenced corrosion in progress where microorganisms gain some benefit from the copper pipe environment. This was measured in the residence where copper was found at 140 and 260 µg/L (Table 3.3) versus 25 µg/L or less in other premise plumbing locations (Tables 3.2 and 3.4).

Lead. Weston is a water system without large sources of leaded materials, so measured lead concentrations were low in the February sampling event. However, under the right conditions, lead from alloys can be elevated as was observed in the stagnating water in Well 5 (Table 3.1).

Calcium dissolution. A purely chemical issue was described in the January report related to the integrity of cement piping and cement-lined piping. If there is a tendency to pull calcium into the water, then the cement structure will weaken and crumble. For asbestos-cement water mains, dissolution of the calcium could lead to release of asbestos fibers into the water. The tendency of the water to dissolve versus precipitate calcium can be determined with the calcium carbonate precipitation index (CCPP) and the Langelier Index (LI). The indices were calculated in this report using the RTW computer software. Table 4.1 lists the indices calculated for three locations in the Weston water system. It is seen that the water in the Weston system has a tendency for calcium to be pulled into it. Further calculations with the computer software shows that this tendency is neutralized if the pH is increased to above 8. However, above a pH of 8, the chlorine disinfection is rendered ineffective. Chlorine is most effective near and below a pH of 7.0. Given the microbiological issues identified in the water system, the effectiveness of the disinfection is extremely important in order to maintain high water quality and the integrity of metal pipes. Therefore, a balance must be made between the two criteria – one set of criteria to protect the cement pipes and one set of criteria to protect the metal pipes. A pH of 7.8 was used in the computer software to lower the tendency to pull in calcium while minimizing the deleterious effect on the disinfection effectiveness. The pH increase lowered the tendency to dissolve calcium. But, in order to neutralize the tendency to pull in calcium, the alkalinity must be increased in the water. Increased alkalinity also buffers pH fluctuation, which controls the many chemical interactions in the water. The more stable the pH, the more stable the water chemistry and water quality.

Table 4.1 Calcium Carbonate Precipitation Potential in Weston Water

Parameter	Well 5	CB 2	IB/Well 2
Total dissolved solids (conductivity/1.56) in mg/L	622	402	559
Temperature in deg C	13.3	10.0	13.4
pH	6.55	7.36	7.08
Alkalinity in mg/L as $CaCO_3$	57	40	78
Calcium (Ca x 2.5) in mg/L as $CaCO_3$	85	57.5	87.5
CCPP in mg/L	-60	-8.8	-23
LI	-1.7	-1.2	-1.0
Modification to pH where LI>0	8.3	8.7	8.1
Modification to pH and alkalinity where LI>0			
pH	7.8	7.8	7.8
Alkalinity in mg/L as $CaCO_3$	160	250	155

CB = Commercial Building
ID = Industrial Building
CCPP = calcium carbonate precipitation potential
LI = Langelier's Index

Section 5: Recommendations

SYSTEM MAINTENANCE

Well Maintenance and Cleaning

Weston has a complex microbiological issue occurring, but the initial progress in remediation and prevention of the issue can be made with cleaning and modification of the wells.

The integrity of each well should first be determined and repairs made to prevent the intrusion of water directly from the surface or from unintended underground sources. In the February sampling event, Well 5 was sampled over short time intervals based on the volume of water in the well and the pumping rate of the well pump. This technique can be applied to the other wells by water utility personnel using field tests only. That is, a well to be studied should be allowed to stagnate for 24 hours.   After the well pump is turned on, successive water samples should be taken at timed intervals selected to capture water from locations within the stagnating well and then out into the aquifer. Water samples should be analyzed on-site for pH, temperature, conductivity, oxidation-reduction potential, and turbidity. The timed sampling can run from one to several hours total in order to characterize the water within the well versus water delivered from the aquifer. Changes in the analyzed parameters should be investigated with further inspection of the well. Changes in the parameters can indicate corrosion of metal components or a breach in the well casing allowing water from unintended sources to enter. Changes in parameters over time as the pump pulls from the aquifer can indicate water from unintended sources entering the water system. Examples of unintended water sources are water from near landfills and near rivers or lakes where both chemical and microbiological contaminants can be drawn into the water system. There are more water quality parameters that could be tested during the timed sampling that can describe a more complete picture of the water quality changes through the well and out into the aquifer. However, the use of the field tests is a relatively inexpensive approach that can be performed by water utility personnel to screen each well for problems and to better guide requests for engineering assistance in working with the wells. Well 2, which supplies water to the Industrial Building, should be the next well to be assessed in this way.

In addition, water in the casing and borehole that is not refreshed routinely should be eliminated. In order to get rid of any zone of stagnating water, well pump configuration modification may be necessary or modification to move fresh water into the stagnation zone may be required.

Also, pump operations can possibly be changed so that the initial plug of water that contains the higher concentrations of metals and microbiological materials can be pumped to waste when the well pump starts up instead of being pumped into the distribution system.

Wells should be cleaned to remove biofilms. Chemical aids, such as sodium hypochlorite, acid, and biofilm-removing chemical, are necessary to loosen the biofilms. However, biofilms also typically require physical scouring to remove them.

After the initial cleaning of wells, routine shock chlorination of wells should be considered.

Uni-directional Flushing

Cleaning water mains can also be a boost to remediating the microbiological issue.

There is already a program of water main flushing in the Village of Weston. In the January report, 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.

In addition, based on the discussion in Section 4, there are most likely very tenacious biofilms in the Weston water system that incorporate iron and manganese within the biofilm structure. This is very difficult to remove as noted for the wells above.

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 (typically greater than 5 fps) 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).

In an alternative perspective, research at the University of Sheffield in England has shown that a high scouring velocity is not necessary. Instead, an increase in velocity and/or change in water flow direction can knock off the loosest debris from pipe walls. But, similar to the scouring velocity concept, it is critical to measure turbidity and to continue a flushing run until turbidity is less than 1 NTU and even lower. In addition, more frequent flushing is required in order to “control” chemical scale and biofilm formation; elimination of chemical scale and biofilm formation is not possible. According to Dr. V. Speight of the University of Sheffield, more frequent flushing to a very low turbidity is “like cutting the grass” in order to control the pipe wall cleanliness. In some water systems, flushing valves have been added in order to perform the routine flushing.

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.

Refer to a video of the Green Bay Water Utility’s experience in uni-directional flushing at https://www.youtube.com/watch?v=vrBACFuQ8tc&feature=youtu.be

Because of the presence of the thick biofilm, it may be necessary to use pigging of the water mains where ever it is possible to do so. Alternatively, the more frequent flushing strategy may result in longer term control of pipe wall accumulations.

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, if possible. 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.

General Notes on Cleaning

After the initial cleaning of infrastructure, a routine maintenance schedule should be established at a frequency that prevents the re-establishment of biofilms. Refer to the on-going monitoring recommendations that can aid in establishing the appropriate frequency for cleaning.

PREMISE PLUMBING MAINTENANCE

Cleaning may also be necessary in premise plumbing. However, the municipal water utility cannot be responsible for work with premise plumbing since it crosses a public/private property line. The cleaning of wells and water mains will improve the water quality in private plumbing systems and lessen the potential for microbiologically influenced corrosion. But, there still can exist conditions in premise plumbing as a function of plumbing design and maintenance that are only in the property owner's control. In these cases, property owner education about water system maintenance can be effective as described below.

Water Service Lines

Some water service lines are oversized for the actual water usage in the building. This is particularly true when a fire suppression system in the building is also connected to the domestic water service line. In these cases, water stagnates in the service line and microbiological issues can initiate there and be passed into the building. Property owners should consider installing a flushing valve after the water meter to routinely run a sufficient quantity of water to change over the volume of water in the service line.

Hot Water Tanks

Hot water systems should be "blown down" monthly in water systems where there is a higher potential for excessive microbiological growth and quarterly or annually in other water systems. This involves a functional drain valve at the bottom of the hot water tank. Take caution with valves that have not been used in a long time as they can leak. As a first step, it is best to have a licensed plumber verify that the valve will work properly. A portion of the bottom tank water should be removed and drained to waste routinely. Start with draining one-tenth of the water tank volume; for a 50-gallon tank, this is 5 gallons of water. Adjust the volume to waste as needed. For example, if the water is greatly discolored, drain until the water is clear. There are more precise ways to perform this operation, but for home owners, this subjective method is better than not blowing down the tank at all.

Water Softeners

Water softeners are not common in the Weston water system since the water hardness does not require their use. But, where softeners are used, models should be used that do not trap water in a stagnating layer inside. An organic acid cleaner approved for water softener media cleaning should be used routinely to not only remove iron from the softener media but also to remove biofilms. The initial cleaning of a softener with biofilms already formed may take repeated cleanings. After that, the automatic introduction of the cleaning chemical into the brine tank will deliver the cleaning chemical in each water softener regeneration cycle. It may be necessary to set the softener for more frequent regenerations and to set the brine hold time in contact with the resin for a longer period. This can be accomplished with the help of a water softener technical representative. A recommended organic acid for water softener cleaning is Crystal Clean (http://www.crystalclean.us/iron-water/?gclid=EAIaIQobChMI4OnN__Oy2gIVgRlpCh1S_whqEAAYASAAEgJ-S_D_BwE)

Special Equipment

The special equipment at Commercial Building 2 is attached to the premise plumbing system. The data indicate that there are biofilms and chemical precipitation that has occurred in the machine. The manufacturer should be consulted for recommended cleaning methods and possibly tubing replacement. The use of an in-line filter before the water enters the equipment can also create microbiological problems with biofilm formation on the filter media. Such filters should be changed frequently, possibly more frequently than recommended by the manufacturer.

General Cleaning of Premise Plumbing

It is possible that some buildings may experience more severe biofilm formation and microbiologically influenced corrosion within the plumbing system. There are techniques to cleaning the systems but much care must be taken to not harm plumbing materials. Chemicals (sodium hypochlorite for disinfection and Clearitas for biofilm removal [http://www.blueearthlabs.com/products/clearitas/]) can be used to soften the biofilms and chemical deposits. Physical scouring, such as air scouring or pigging, must accompany the chemicals in order to remove the deposits.

Heat Exchanger Piping at the Industrial Building

Well 2 that serves the Industrial Building should be inspected and cleaned as described previously. It would be of interest to look into the addition of UV disinfection as an additional barrier to microorganisms that would be transferred from the well into the Industrial Building's piping although this would be experimental. However, routine shock chlorination of the well may be sufficient in controlling the excessive growth of microorganisms in the well.

The heat exchanger piping should be cleaned with appropriate concentrations of sodium hypochlorite and Clearitas (or its sister product, Floran) and physical scrubbing with pigging or air scouring. Caution must be taken in that cleaning can remove corrosion debris that is plugging up pipe wall holes and more leaks could become apparent.

General notes on cleaning

After the initial cleaning of piping and equipment, a routine maintenance schedule should be established at a frequency that prevents the re-establishment of biofilms. Refer to the on-going monitoring recommendations that can aid in establishing the appropriate frequency for cleaning. For residential plumbing, it is not practical for a home owner to routinely monitor the water. Routines at that level may be selected on a subjective basis. For commercial buildings, monitoring will indicate what frequency of cleaning is necessary.

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. 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

Section 4 described the need to boost pH from the pH the wells deliver in order to protect cement materials in the water system, but to maintain the pH low enough for chlorine disinfection to continue to be effective in order to fight the microbiological issues in the system. A pH of 7.8 was suggested as a compromise.

Alkalinity Adjustment

The discussion in Section 4 also recommended raising the alkalinity of the water. An increased alkalinity would buffer pH so that it would vary through a narrower range. An increased alkalinity would also provide more protection for cement materials in the water system.

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 difficulties. In the past, the personnel of the Weston water department expressed the impracticality of these methods in a small water system. If modern chemical handling techniques cannot overcome issues experienced in the past, then a calcite contactor should be considered for raising the alkalinity.

With a calcite contactor, 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 7.8 and to increase the alkalinity enough so that the pH stays at that level or just below, if possible. The computer software used in Section 4 showed that an alkalinity increase up to around 200 mg/L as $CaCO_3$ is suggested.

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. There are issues with the use of polyphosphate for sequestration as discussed in the January report. 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 phasing out of polyphosphate should be performed gradually so as not to disrupt existing accumulations in the water system. The phasing out period can be shortened with a cleaner water system.

As discussed previously, cleaning and modification of wells can prevent iron and manganese from being introduced from corrosion inside the well. However, manganese appeared to be a problem introduced to the water system from the geology of the aquifer and will require a water treatment process for removal.

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

Well 5 was assessed in this project and will require manganese removal through a treatment process. The other wells should also be assessed for their contribution to manganese in the water system. Manganese removal of one or more wells may be necessary.

Note that manganese removal alone will not solve the water quality issues in the Weston water system. Manganese removal must be accompanied by routine system well and water main cleaning and the prevention of microbiologically influenced corrosion.

After the introduction of a manganese (and iron) removal filter, there must be routine vigilance that the filter media does not become covered with biofilms and become an incubator for microorganisms and their products passed into the distribution system. Routine media cleaning beyond backwashing and monitoring must be part of the operations plan.

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. 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

This report has recommended initial and routine cleaning of water system components. Monitoring of certain parameters are necessary in order to trigger another cleaning event and establish a typical frequency of maintenance.

Data should be entered into spreadsheets so that quick graphing and analysis will be possible. (Databases are better for storing data but many water utilities do not have this capability.) Graphs of measured parameters over time are important to study daily, weekly, or monthly. Data should be studied quarterly at a minimum and corrective actions taken upon viewing undesired behavior on the graphs.

The following parameters should be tracked using field or on-line analysis where possible:

- Wells during startup and after running for over an hour (See a description of this procedure under System Maintenance earlier in this chapter. This could be done annually at a minimum in order to detect changes in wells over time by comparing data to historical data.)
    - Turbidity
    - Conductivity
    - Oxidation-reduction potential
    - pH and temperature
- Water mains for each flushing run (Data could be compared to historical data per flushing run to optimize efforts in cleaning water mains.)
    - Beginning and ending turbidity
    - Other flushing operational data such as velocity of flushing water and time to achieve the final turbidity
- Residential hot water tanks and softeners
    - It is not practical to measure parameters in residences unless there is a severe problem.
    - For hot water tanks, blow down one-tenth of tank or until clear monthly to annually.
    - For water softeners, use Crystal Clean-style organic acid to clean media for each regeneration
- Commercial hot water tank blowdown and softener discharge
    - Turbidity
    - Conductivity
    - Oxidation-reduction potential

- Commercial piping with sample ports at critical segments
  - Turbidity
  - Conductivity
  - Oxidation-reduction potential
- Water service lines with sampling at the location that water enters the building
  - Turbidity
  - Conductivity
  - Oxidation-reduction potential
  - pH
- Water treatment chemicals for disinfection, pH, alkalinity, and phosphate at the discharge of each well after dosing
  - Daily chemical dosing parameters should be recorded and graphed. This information is recorded for a monthly regulatory report anyway. Dosing parameters for pH (caustic soda), chlorine (sodium hypochlorite), alkalinity 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.
- Iron and manganese removal filter – before and after the filter
  - Iron
  - Manganese
  - Turbidity
  - Conductivity
  - Total Organic Carbon
- Distribution system general water quality where Total Coliform Rule sampling sites and/or past iron monitoring sites can be conveniently used
  - Free chlorine concentration
  - Turbidity
  - Conductivity
  - Iron and manganese (optional)
  - Disinfection by-products (TTHM and HAA5), where regulatory sampling sites can be used but perhaps more frequently
- Watershed contaminants from the discharge of each well
  - Chloride
  - Nitrate