Evaluating the Impacts of Changing Water Quality on Corrosion Control

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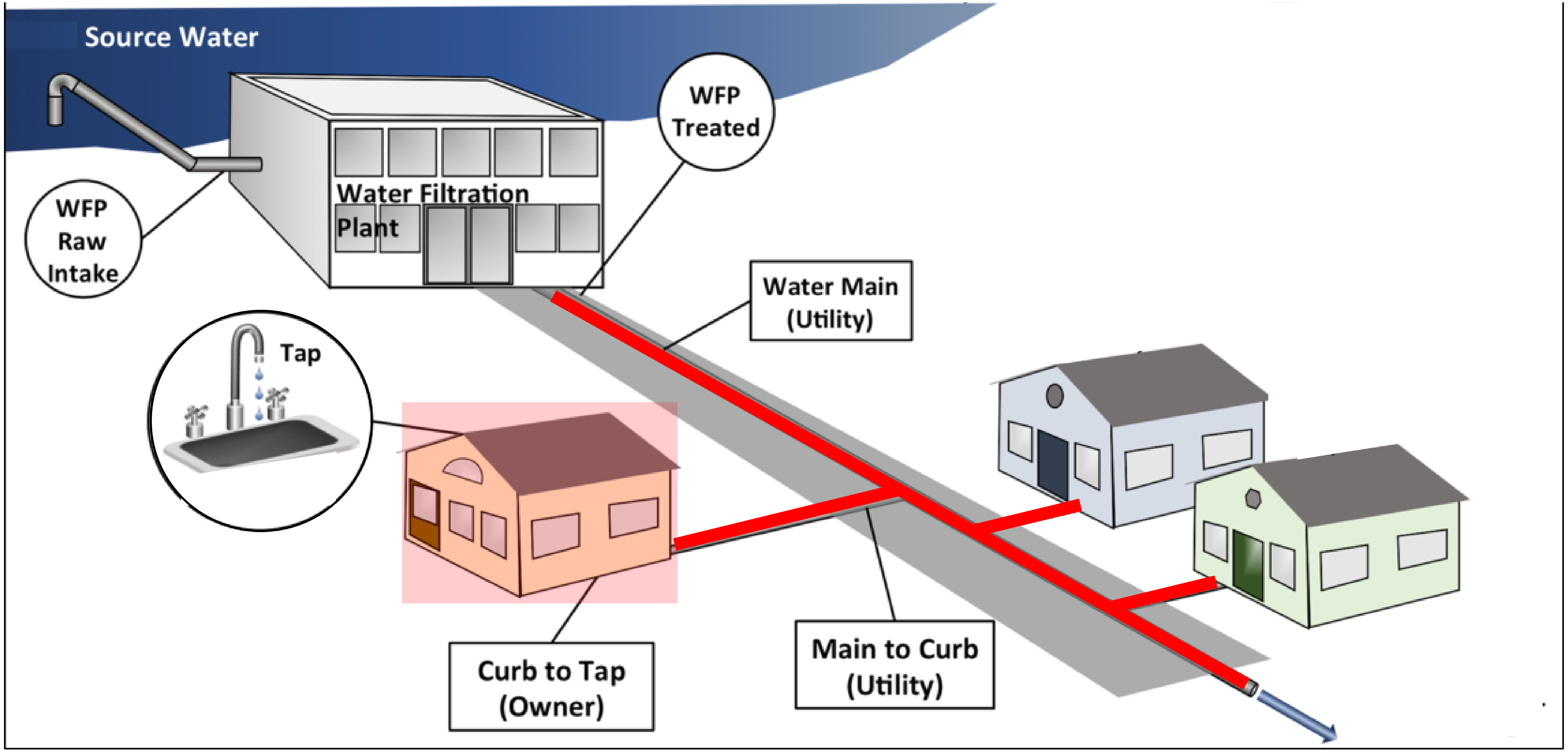
November 9, 2022

PRESENTATION OUTLINE

- Corrosion in the distribution system
    - What is corrosion in the distribution about?
    - Why does it matter?
    - What affects corrosion?
    - How is corrosion potential evaluated?
        - Case study: Tottenham, New Tecumseth, Ontario
    - How is the corrosion control chemical selected?
        - Case study: Windsor Lake Water Treatment Plant, City of St. John’s, Newfoundland

WHAT IS CORROSION IN THE DISTRIBUTION ABOUT?

Corrosion in the distribution system refers to transfer of metal from pipe walls into the bulk water that results in elevated metal concentrations in drinking water



Adapted from USGS 2015, https://www.usgs.gov/media/images/idealized-diagram-a-public-water-supplys-water-distribution-system

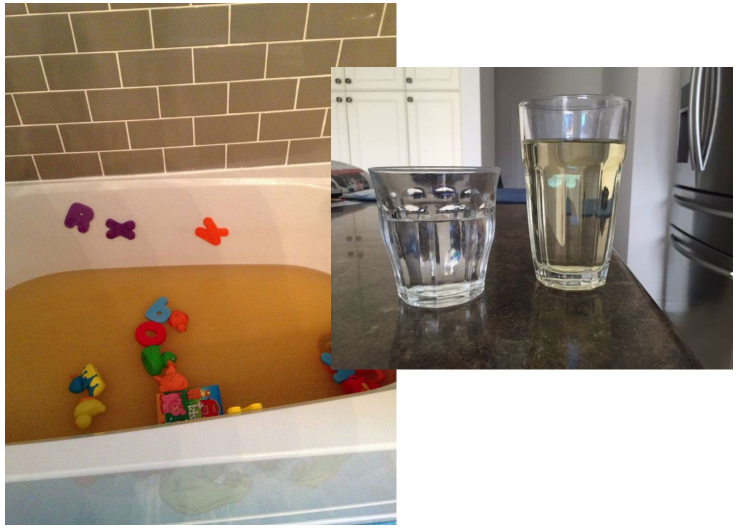
WHY DO WE CARE?

- Main concerns of corrosion in distribution piping:
  - Loss of pipe mass leading to structural weakening of pipes, watermain leaks
  - Tuberculation limiting the hydraulic capacity of pipes and increase head loss
  - Release of metal ions leading to coloured water, T&O issues, and or/elevated lead and copper

1. Structural weakening of pipes

esemag.com

2. Tuberculation



Release of metal ions

WHAT AFFECTS CORROSION

- Water Quality Parameters
  - pH, alkalinity
  - Dissolved inorganic carbon
  - Hardness
  - Oxidants (e.g. dissolved oxygen, chlorine, chloramine)
  - Anions (e.g. sulfide, chloride, sulfate)
  - Temperature
- Pipe material
- Hydraulic conditions

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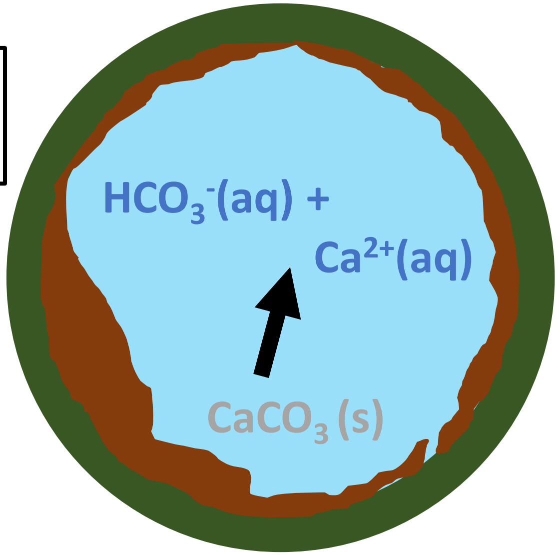
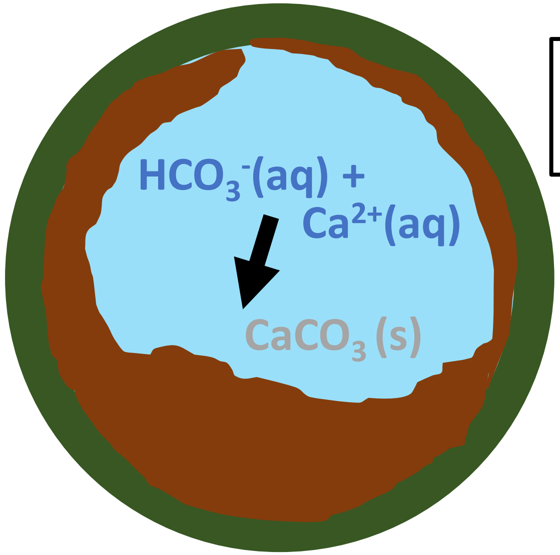
CORROSION INDICES – CALCIUM CARBONATE

Corrosion index	Calculation Method	Application
Langelier Saturation Index	$LSI = pH_{measured} - pH_{calulated\ saturation}$	- Historically commonly used corrosion indices, which estimate the extent of calcium carbonate precipitation and dissolution in the distribution system - Have not been found to strongly correlate with actual corrosion rates
Calcium Carbonate Precipitation Potential	Iterative calculations	
Ryznar Stability Index	$RSI = 2\ pH_{calulated\ saturation} - pH_{measured}$	

Corrosive (dissolution)

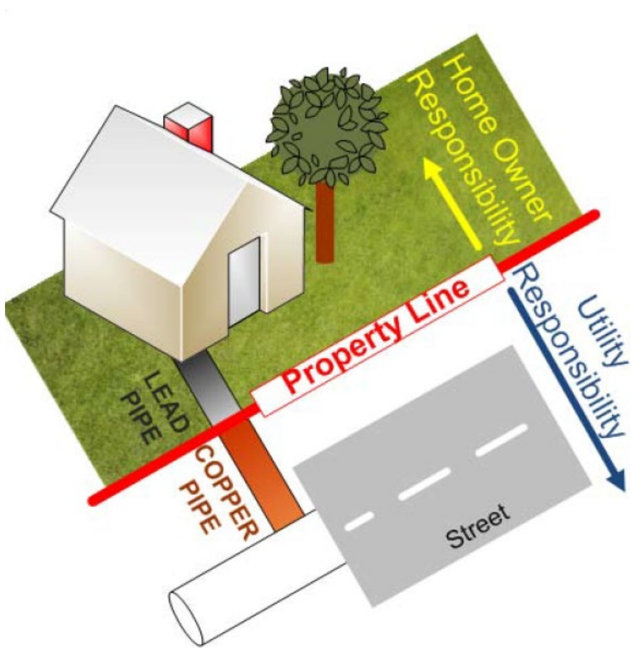




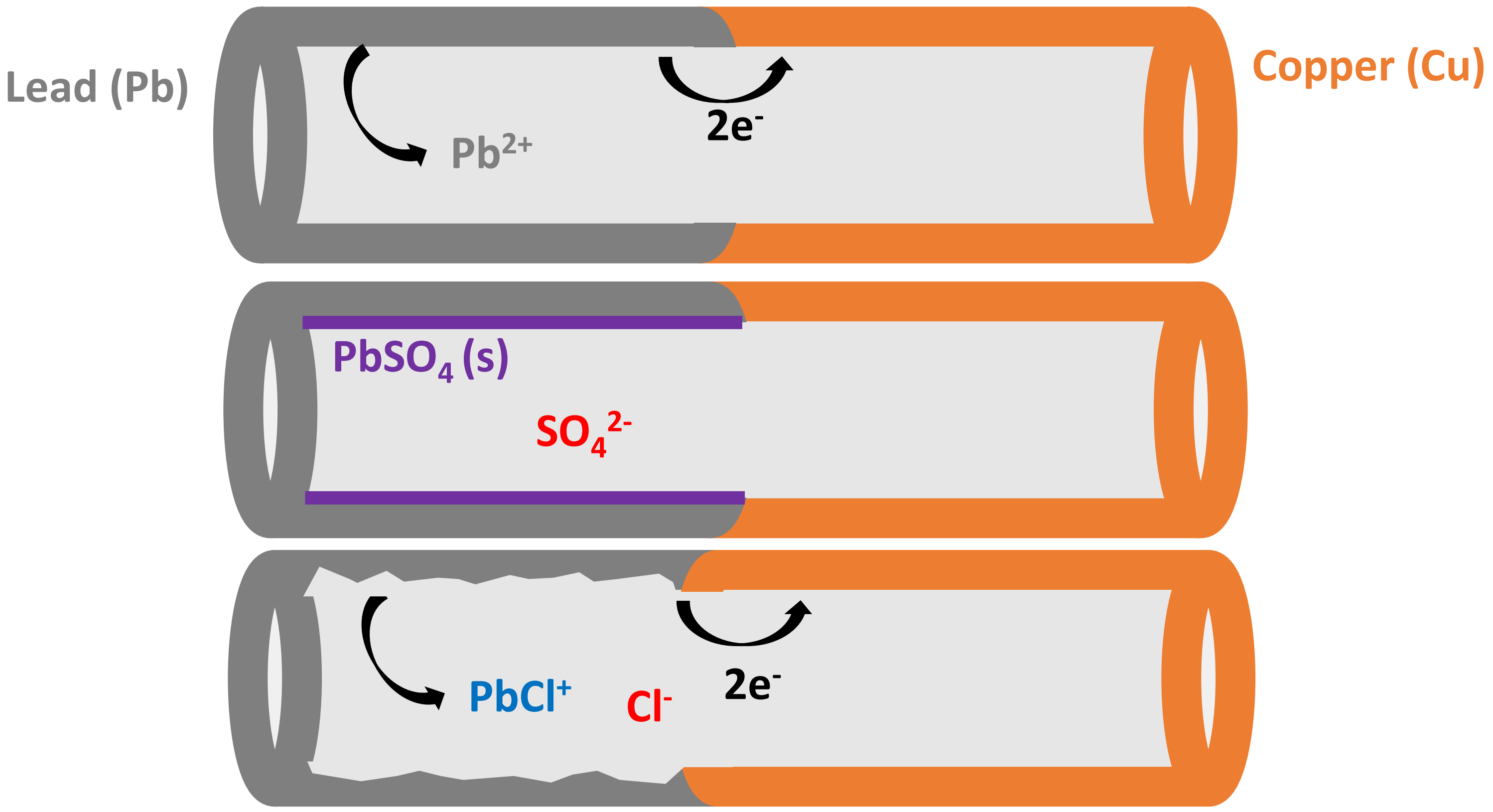
Scaling (precipitation)

CORROSION INDEX – CHLORIDE TO SULFATE MASS RATIO

Corrosion Index	Calculation Method	Application
Chloride to Sulfate Mass Ratio (CSMR)	$CSMR = \frac{Cl^{-}(\frac{mg}{L})}{SO_4^{2-}(\frac{mg}{L})}$	Correlated with lead release, where lead solder or partially replaced lead pipe is used to connect copper pipes



Water Research Foundation #4088, 2010



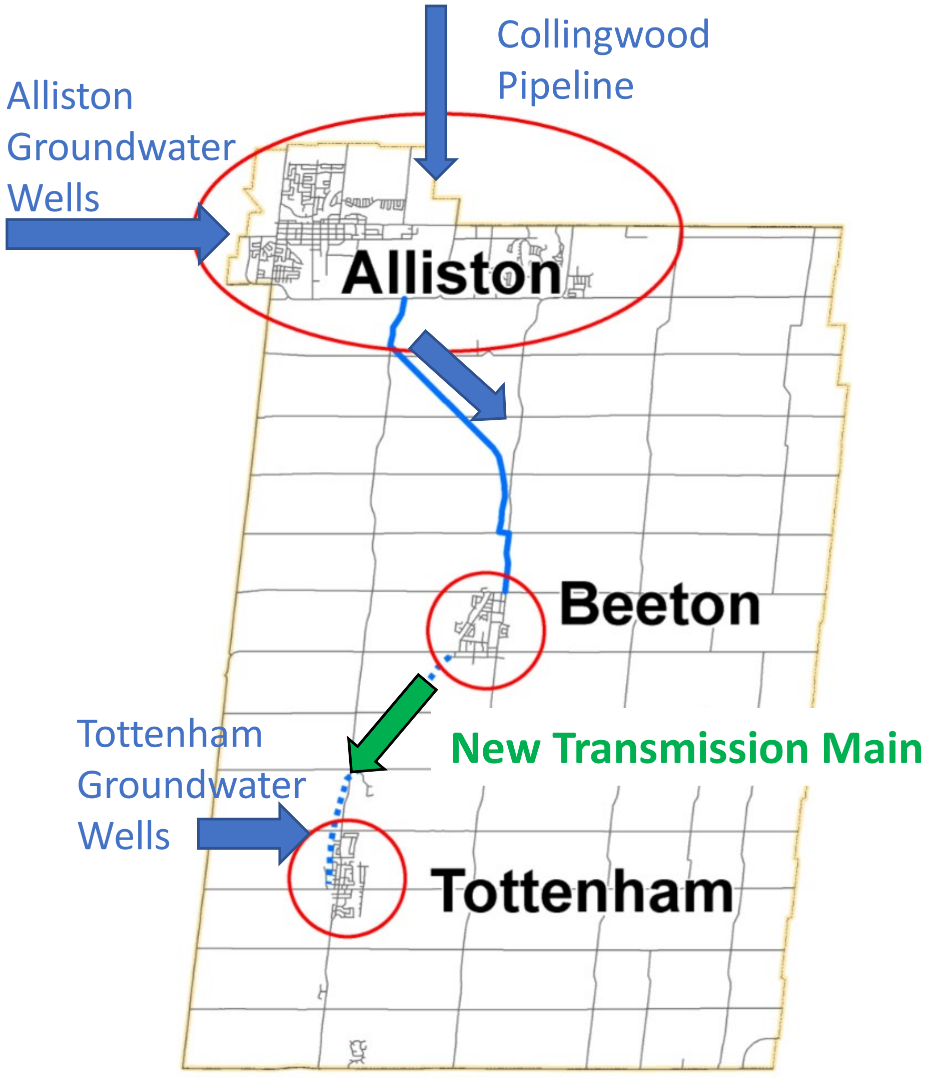
CORROSION METAL RELEASE MODELS

Corrosion Index	Calculation Method	Application
Red water (iron release model)	$Fe = \frac{0.0132\ (Cl)^{0.485} Na^{0.561} {SO_4^{2-}}^{0.118} DO^{0.967} T^{0.813} HRT^{0.836}}{10^{1.321} Alk^{0.912}}$	Alternative indicators of corrosion potential, developed from pipe loop studies
Lead release model	$Pb = (CF) 1.027^{T-25} Alk^{0.677} pH^{-2.726} Cl^{1.462} {SO_4^{2-}}^{-0.228}$	
Copper release model	$Cu = T^{0.72} Alk^{0.73} pH^{-2.86} {SO_4^{2-}}^{0.1} {SiO_2}^{-0.22}$	

https://doi.org/10.1002/awwa.1127

TOTTENHAM - INTRODUCTION

- Existing Tottenham water system is fed by four ground water wells
- **New Tottenham Transmission Main** is being connected to the Beeton water supply (predominantly surface water from Collingwood)
- Tottenham groundwater wells will remain as a backup supply for the Town
- Tottenham groundwater will be blended with Beeton supply in the event of very high demands
- Significant changes in water source and treatment can change the corrosivity of the water
- During the switch-over to the Beeton water supply, process changes may be required to accommodate varying water quality between systems



METHOD

- Water quality tests were conducted on samples collected at locations that represent water from Beeton (predominantly Georgina Bay water) and Tottenham (ground water) that may be blended in the future
- Blend characteristics were determined based on:
  - mass balance calculations for conservative parameters (e.g. chloride)
  - AWWA TetraTech Rothberg Tambuirini and Winsor (RTW) Model for pH

	Water Source	**Blend Percentage**				
	Tottenham	**100%**	**75%**	**50%**	**25%**	0%
	Beeton	0%	**25%**	**50%**	**75%**	**100%**
pH		8.14	8.13	8.11	8.08	8.04
Alkalinity	$CaCO_3$ mg/L	205	177	150	122	94
Calcium	$CaCO_3$ mg/L	105	85	66	47	28
Chloride	mg/L	58	47	36	25	14
Sulfate	mg/L	0.45	2.92	5.4	7.9	10.34

RESULTS

Corrosion indices/metal release model	Guidelines/Target	Water Source	Blend Percentage				
		Tottenham	100%	75%	50%	25%	0%
		Beeton	0%	25%	50%	75%	100%
Calcium Carbonate Precipitation Potential (CCPP)	Scaling (protective): >0 Passive: 0 to -5 Mildly corrosive: -5 to -10 Corrosive: <- 10		14.4	8.9	4.4	0.5	-2.7
Langelier Saturation Index (LSI)	Positive value: deposition of CaCO$_3$ Negative value: dissolution of CaCO$_3$ Recommended to be -0.5 to 0.5		**0.57**	0.45	0.28	0.05	-0.31
Ryznar Stability Index (RSI)	Scaling (protective): >7 Passive: 5 to 7 Corrosive: <5		6.99	7.23	7.54	7.98	8.67

RESULTS

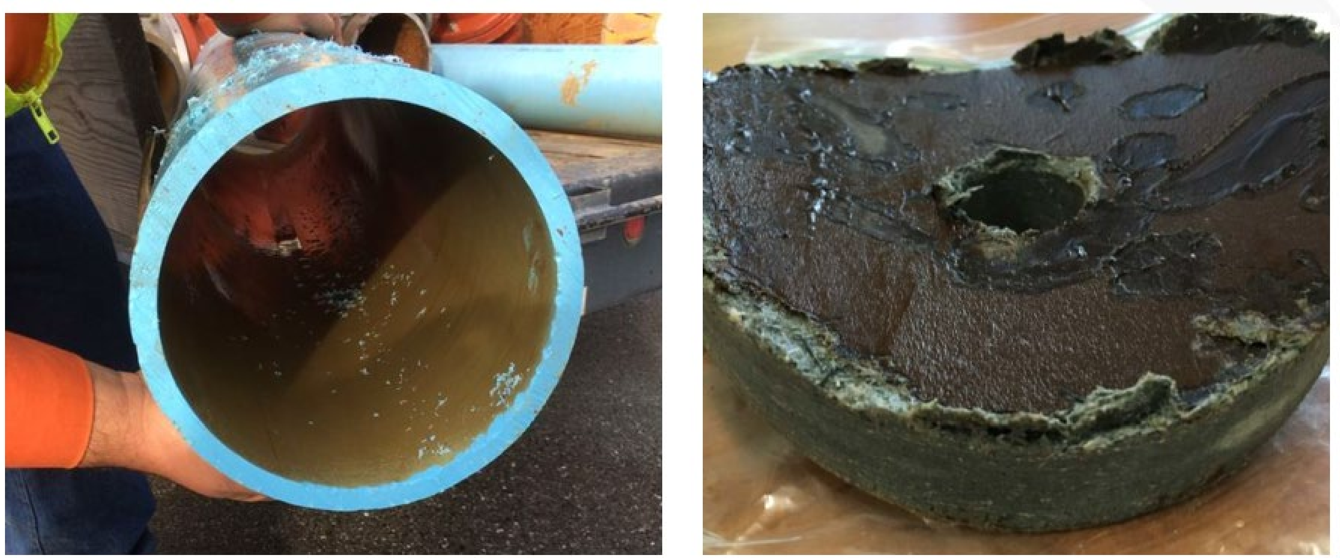
Corrosion indices/metal release model	Guidelines/Target	Water Source	Blend Percentage				
		Tottenham	100%	75%	50%	25%	0%
		Beeton	0%	25%	50%	75%	100%
Chloride-Sulfate Mass Ratio (CSMR)	No concern: < 0.2 Significant concern: 0.2 to 0.5 Serious concern: >0.5 and <50 mg/L alkalinity		**130**	**16**	**7**	**3**	**1**
Iron release (mg/L)	Aesthetic objective: ≤ 0.3 mg/L		0.07	0.09	0.10	0.09	0.07
Lead release (ug/L)	≤ 10 µg/L		4.9	2.4	1.3	0.6	0.2
Copper release (mg/L)	Aesthetic objective: ≤ 1.0 mg/L Maximum acceptable concentration (MAC): 2 mg/L		0.55	0.70	0.77	0.82	0.87

RESULTS – CSMR AND LEAD RELEASE

- CSMR is applicable for lead-copper connections
- Town has advised that lead piping has not been found in previous studies. Presence of lead pipes in unknown
- Lead testing conducted by the Town in 2008, 2011, 2014, and 2017 showed lead levels (0-5 ug/L) below the allowable concentration (10 ug/L)
- The calibrated lead release model indicated that the expected lead levels in all blends (0-5 ug/L) are below the allowable concentration (10 ug/L).
- More importantly, the lead release model indicates the expected lead release decreases with increasing percentage of Beeton water.

LEGACY MANGANESE

- Legacy manganese is manganese that accumulates in the distribution system and leach out when the system destabilizes
- Release of legacy manganese can lead to coloured water events and exposure to regulated heavy metals that co-accumulate with manganese
- Legacy accumulation in the Tottenham distribution is possible given that the groundwater has >0.02 mg/L manganese



AWWA Research Webinar May 2021

RECOMMENDATIONS

- Prior and after the switchover, conduct flushing of the distribution system. Unidirectional flushing at velocities greater than 1.8 m/s is preferred.
- Maintain chlorine residual above 0.4 mg/L throughout the distribution system
- Regular monitoring of lead, copper, manganese, iron and other relevant water quality parameters before and after transitioning from Tottenham to Beeton water

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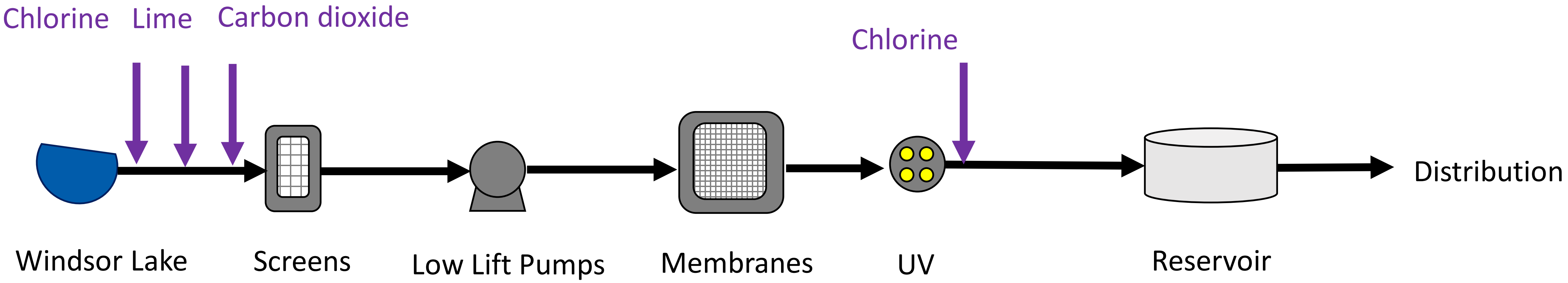
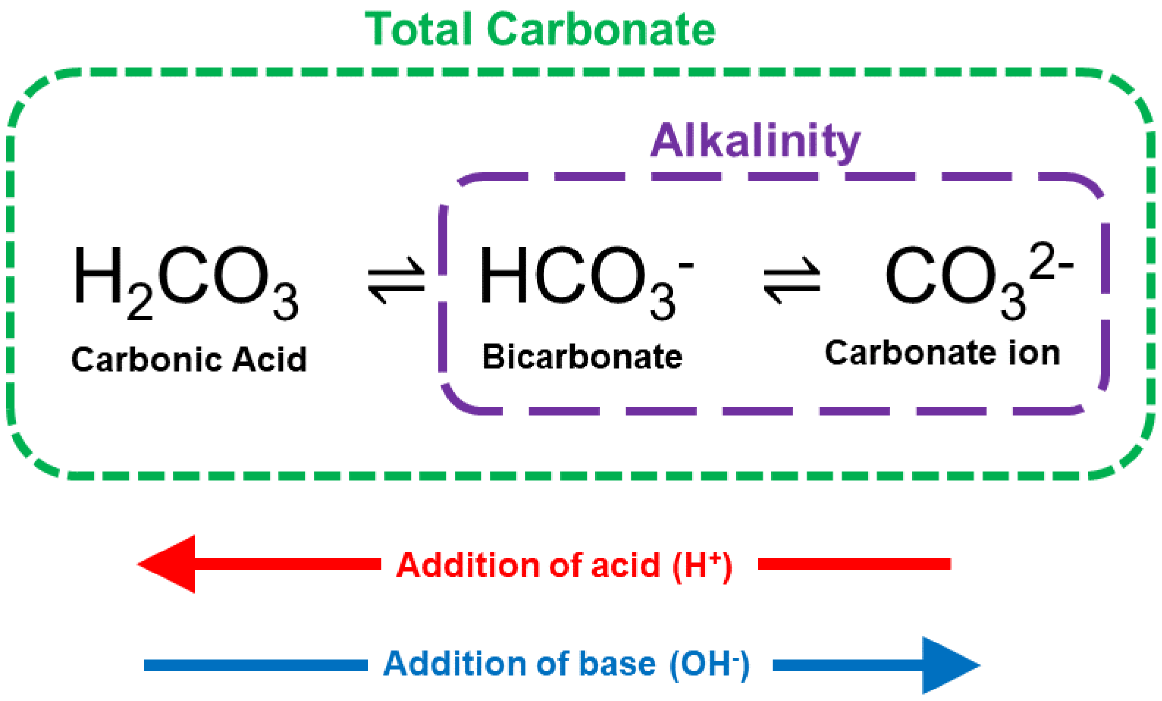
WINDSOR LAKE WTP INTRODUCTION

- Addition of lime prior to membrane filtration poses O&M issues with the membranes
- Target alkalinity (35 mg/L) and pH (8) cannot be met



PH AND ALKALINITY

- pH
  - High pH typically reduces the solubility and by extension, the release of metals from pipes
  - High pH can lead excessive calcium carbonate precipitation
- Alkalinity
  - Measure of the capacity to resist pH



Total Carbonate

Alkalinity

$H_2CO_3 \rightleftharpoons HCO_3^- \rightleftharpoons CO_3^{2-}$

Carbonic Acid **Bicarbonate** **Carbonate ion**

Addition of acid (H^+)

Addition of base (OH^-)

METHOD

1. Use AWWA RTW model to estimate require chemical doses to meet target pH and alkalinity. Compare to previously conducted bench-scale testing results
2. Compare pros and cons, capital and operational costs for each chemical

Chemical	Alkalinity added (+) or consumed (-) (mg/L $CaCO_3$ per mg/L of chemical)
Lime	+1.35
Caustic Soda	+1.25
Soda Ash	+1.94
Baking Soda	+0.6
Chlorine	-1.41

RESULTS

Chemical	Chemical Reaction	Purpose	Advantages (+) Disadvantages (-)	Estimated dose (mg/L)	Annual chemical cost ($)	Process equipment cost ($)
Hydrated Lime $Ca(OH)_2$	$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$	Increase pH	+ Operator familiarity with chemical - Low solubility - Often results in higher turbidity in finished water - High attraction to moisture in atmosphere - Requires dust control - Tendency for scaling/plugging of feed lines	30	$0.58M	$1.08M
Caustic Soda (sodium hydroxide) NaOH	$NaOH \rightarrow Na^+ + OH^-$		+ Low O&M feed system - Hazardous chemical - High freezing point (14°C)	30	$1.81M	$0.7M

RESULTS

Chemical	Chemical Reaction	Purpose	Advantages (+) Disadvantages (-)	Estimated dose (mg/L)	Annual chemical cost ($)	Process equipment cost ($)
Soda ash (sodium carbonate) Na_2CO_3	$Na_2CO_3 \rightarrow 2Na^{2+} + CO_3^-$	<u>Increase</u> pH + Add carbonate	+ Nonhazardous chemical + Relatively easy to handle and dose - Requires dust control	40	$1.60M	$1.03M
Baking soda (sodium bicarbonate) $NaHCO_3$	$NaHCO_3 \rightarrow Na^+ + HCO_3^-$		+ Nonhazardous chemical - Requires dust control	60	$1.81M	$1.05M
Carbon dioxide CO_2	$CO_2 + OH^- \rightarrow HCO_3^-$	<u>Decrease</u> pH + Add carbonate	+ Useful for trimming pH when used with other chemicals like hydrated lime and caustic soda	12-30	$0.5-1M	N/A

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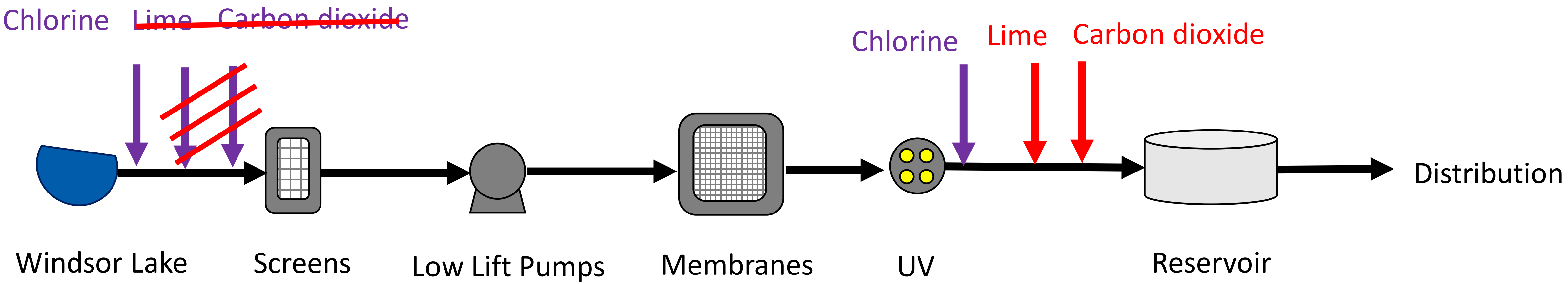
WINDSOR LAKE WTP

arva



Chlorine ~~Lime~~ ~~Carbon dioxide~~

Chlorine Lime Carbon dioxide

Windsor Lake

Screens

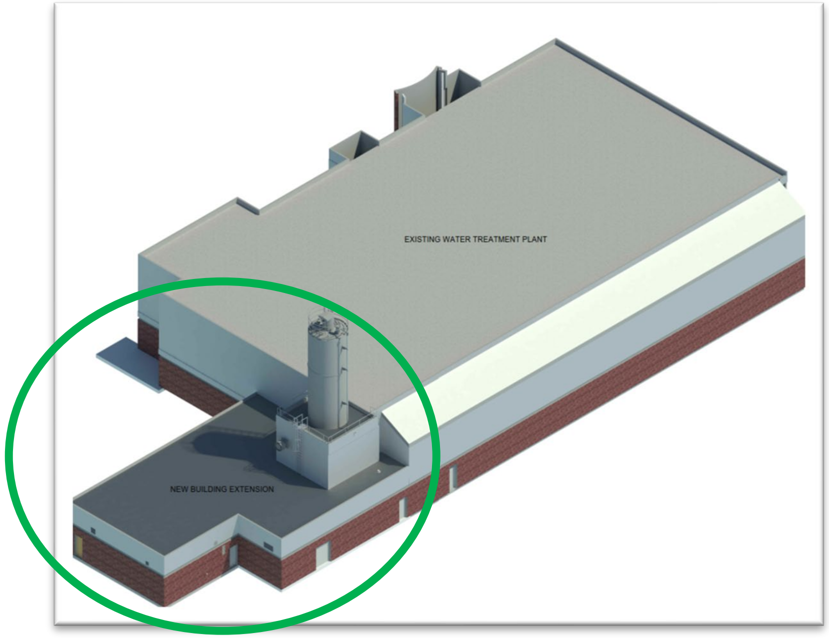
Low Lift Pumps

Membranes

UV

Reservoir

Distribution



KEY TAKEAWAYS

- Significant changes in water source and treatment can change the corrosivity of the water
- Calcium carbonate based indices have not been found to strongly correlate with actual corrosion rates
- Metal release models are useful tools to predict corrosion in the distribution system
- Legacy manganese needs to be considered as part of corrosion control
- Chemical selection for alkalinity and pH adjustment depends on carbonate chemistry, costs, and O&M needs