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Legacy Aluminum in the Distribution System: Impacts on Corrosion Control with Orthophosphate

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Hamilton ENWIN

Presentation Outline

- Legacy aluminum in the distribution system
  - How does it get there?
  - What are the impacts?
- Implementing orthophosphate in the presence of legacy aluminum: case studies
  - Selecting the appropriate orthophosphate dosage & developing an implementation plan
  - Observed lead reduction at 2 mg/L as PO_4
  - Observations of secondary impacts and their control
- Summary

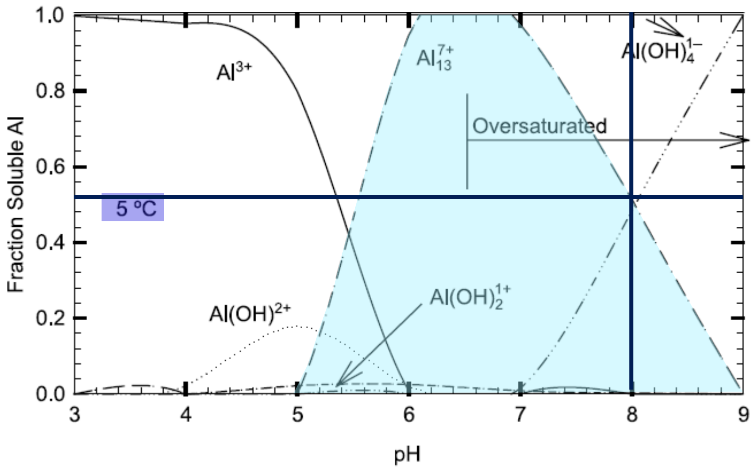
Legacy Aluminum in the Distribution System

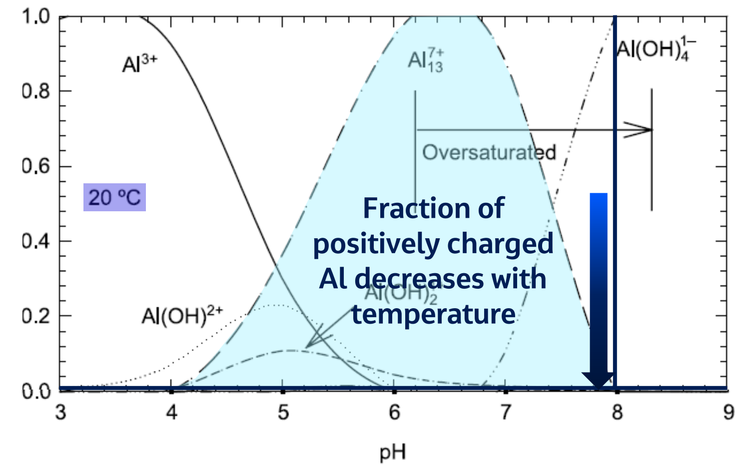
Sources and Impacts

How Does Aluminum Get in the Distribution System?

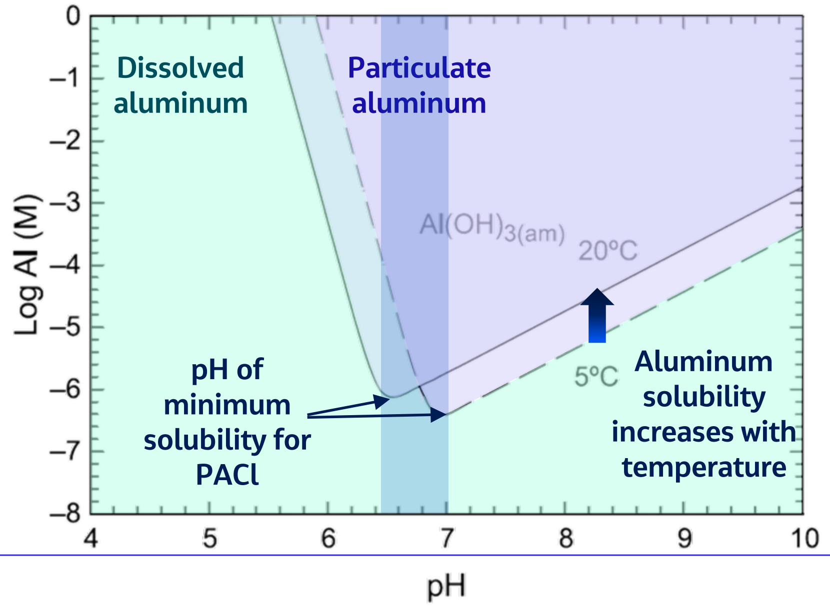
- Aluminum can be present in treated water from the use of **aluminum-based coagulants** in a **non-optimized coagulation** process
- The **speciation** and **solubility** of coagulants are impacted by **temperature and pH**, which vary seasonally
- Many WTPs treating Great Lakes waters experience **high residual dissolved aluminum in treated water**, particularly in the **summer months**
- Aluminum can also be released in localized areas from **cementitious pipes** and **cement mortar linings** when watermains are relined

Theoretical aluminum speciation for PACl, Al_T = 1 mg/L. Adapted from Pernitsky and Edzwald, 2006





Theoretical solubility diagram for PACl in deionized water Adapted from Pernitsky and Edzwald, 2006



What Happens to Dissolved Aluminum in the Distribution System?

- **Post-precipitation** of dissolved aluminum and **flocculation** can occur in the distribution system if the pH decreases below the pH of coagulation
- Deposition of **gelatinous aluminum-containing substances** or **aluminum-containing crystalline solids** in watermains may also occur
- **Accumulation** can occur in areas of low flow, such as dead-ends and reservoirs
- **Release** of deposits at **very high concentration** can occur from hydraulic surges such as watermain breaks

Example of gelatinous aluminum deposit

Example of aluminum silicate scale

Flush water containing 38 mg/L aluminum

What Are the Impacts of Aluminum in the Distribution System?

Hydraulic/ Pressure	• **Increased hydraulic friction from deposits/scales**, reducing the distribution system's carrying capacity, increasing pressure losses, and increasing the energy required for pumping • Deposition within water meters and service lines can cause **water meter malfunctions and low household water pressure**
Water Quality	• Floc and released deposits can **impart turbidity and/or milky colour** to the water, causing **aesthetic impairment** • Floc, deposits, and scales can **provide a substrate upon which other trace metals can adsorb or co-precipitate** • Accumulated trace metals can **be released at high concentrations** due to desorption or particle detachment • **Dissolution of previously precipitated deposits and scales** can be a source of aluminum
Secondary Disinfection	• High levels of aluminum may interfere with secondary disinfection due to **enmeshment and protection of microorganisms**
Corrosion Control	• The reaction of orthoPO_4 with aluminum produces a **precipitate that can give water a "milky" appearance** • Aluminum can behave as a sink for dissolved orthoPO_4, **reducing the residual available for corrosion control** • Deposits can lessen the efficacy of corrosion control by **interfering with the development of protective corrosion scales** • Impacts expected with orthoPO_4 >3.0 mg/L as PO_4 and aluminum >0.1 mg/L

Guidelines for Aluminum in Treated Water and Distribution System

Guideline	Value	Applicability	Purpose
USEPA Secondary MCL	50 to 200 µg/L	Applies to point-of-entry	Prevent discoloured water
Operational Guideline (Ontario) *Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines (2003, rev. 2006)*	100 µg/L	Applies to point-of-entry	Prevent coating of pipes in the distribution system, interferences with certain industrial processes, and flocculation in the distribution system.
Operational Guideline (Health Canada) *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Aluminum (2021)*	100 µg/L	Applies to **point-of-entry and distribution system**. For facilities that use aluminum-based coagulants, the OG applies to a locational running annual average calculated based on daily samples that are averaged on a monthly basis.	Minimize accumulation and **release of aluminum and co-occurring contaminants** and coating of pipes and appurtenances.
Maximum Acceptable Concentration (Health Canada) *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Aluminum (2021)*	2,900 µg/L	Applies to the **distribution system and point-of-consumption**. For facilities that use aluminum-based coagulants, the MAC applies to a locational running annual average calculated based on a minimum of monthly samples collected from the distribution system.	**Health-based** (neurological effects observed in rats)

Consider a target <100 µg/L when implementing phosphate-based corrosion control

Implementing Corrosion Control in Systems With Legacy Aluminum

Strategies and Outcomes

System Characteristics

	Windsor	Hamilton
Serviced population	~270,000	~570,000
Size of distribution system	~1,100 km	~2,000 km
Source water	Detroit River (Lake St. Clair)	Lake Ontario
pH control	CO_2 ahead of coagulation	None
Corrosion control treatment	Orthophosphate, 2.0 mg/L as PO_4	Orthophosphate, 2.1 mg/L as PO_4
Year implemented	August 2016	November 2018
Average treated water pH	7.0	7.8
Average treated water alkalinity	86 mg/L as $CaCO_3$	86 mg/L as $CaCO_3$
Secondary disinfectant	Free chlorine	Chloramine

Corrosion Control Approach

Plan

- Both systems completed a **Corrosion Control Plan** per MECP's *Guidance Document for Preparing Corrosion Control Plans for Drinking Water Systems*
- **Phosphate-based corrosion control** identified as preferred for both systems

Study

- Both systems completed a **Pipe Loop Study** to identify the preferred treatment chemical, dosage, and pH
- Hamilton completed a **flushing study** which confirmed presence of **legacy aluminum in distribution system**
- **Orthophosphate dose targets** confirmed at 2.0 mg/L as PO_4 (Windsor) and 2.1 mg/L as PO_4 (Hamilton) based on these studies and lessons learned from **Washington DC**

Implement

- **Pre-filter orthoPO_4 dosing** in Hamilton to mitigate aluminum impact
- **Flushing** before/during/after implementation to mitigate secondary impacts

Monitor

- Both systems implemented a distribution system water quality monitoring program to **assess corrosion control effectiveness and aesthetic impacts**
- Hamilton installed **pipe loop monitoring stations** in the distribution system

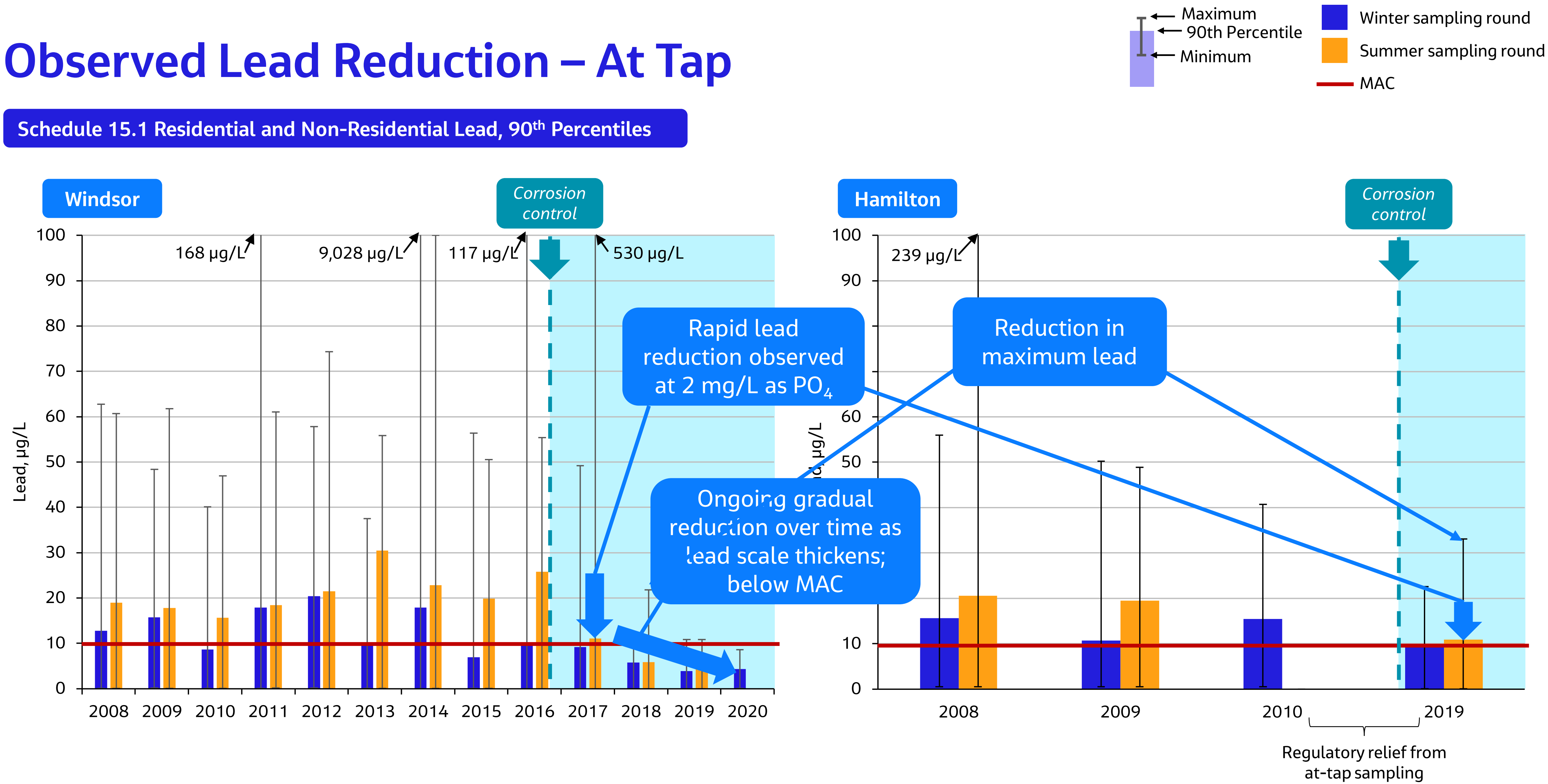
Milky water in Washington, DC due to Al-PO_4 precipitation

Washington DC

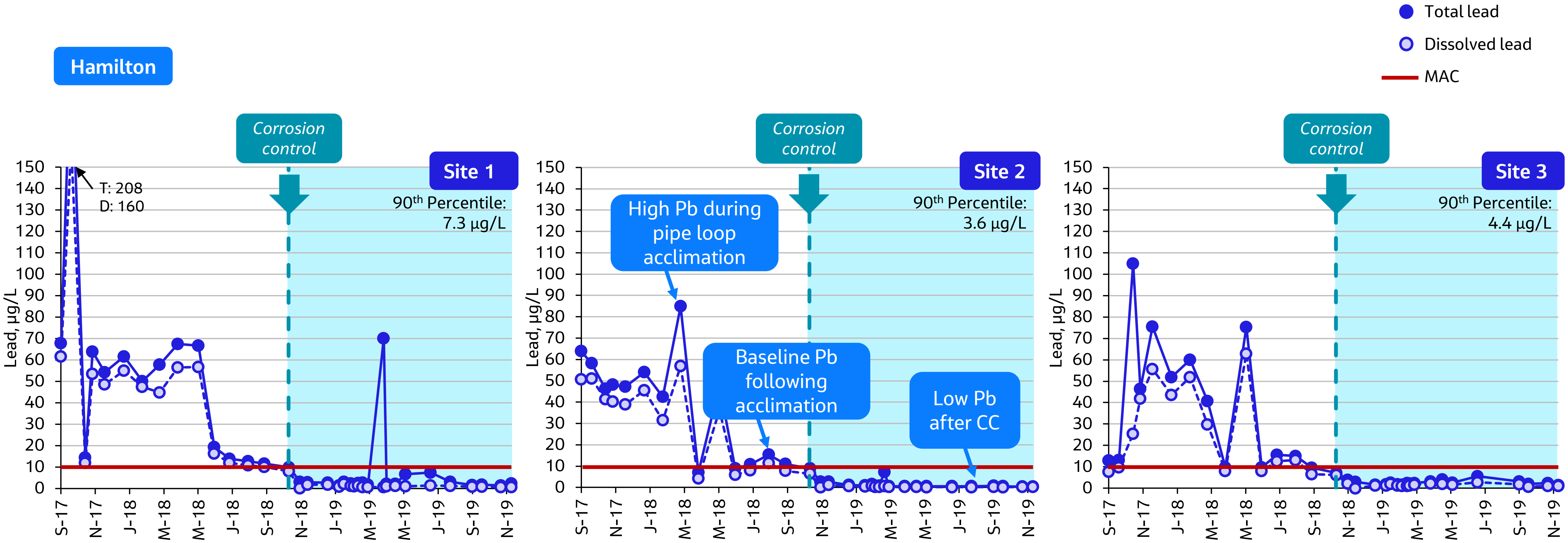
- *Lead release event due to the switch from free chlorine to chloramine in 2001*
- *Initial orthoPO_4 dosage of **3.5 mg/L** in 2004*
- *After 1.5 years, reduced to **2.5 mg/L** due to **widespread milky water episode** resulting from orthoPO4 precipitation with aluminum (treated water dissolved aluminum ~100 µg/L)*

Observed Lead Reduction – At Tap

Schedule 15.1 Residential and Non-Residential Lead, 90th Percentiles



Observed Lead Reduction – Pipe Loop Monitoring Stations



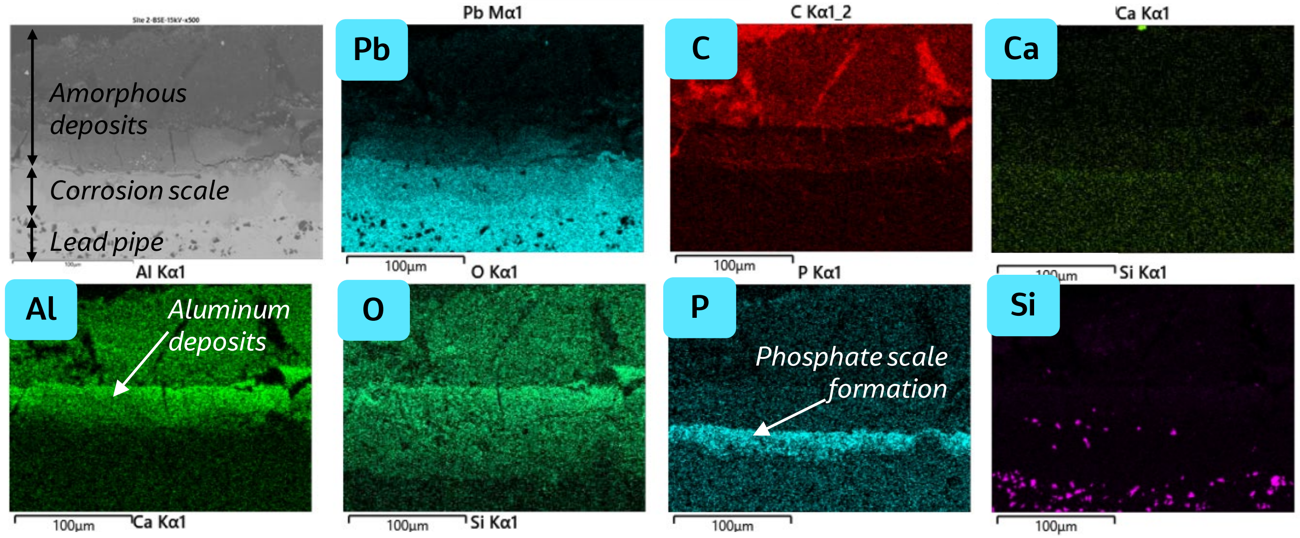
Pipe loop monitoring stations confirmed results observed from at-tap sampling
Post-corrosion-control lead consistently below MAC

Evidence of Lead-Phosphate Scale Formation

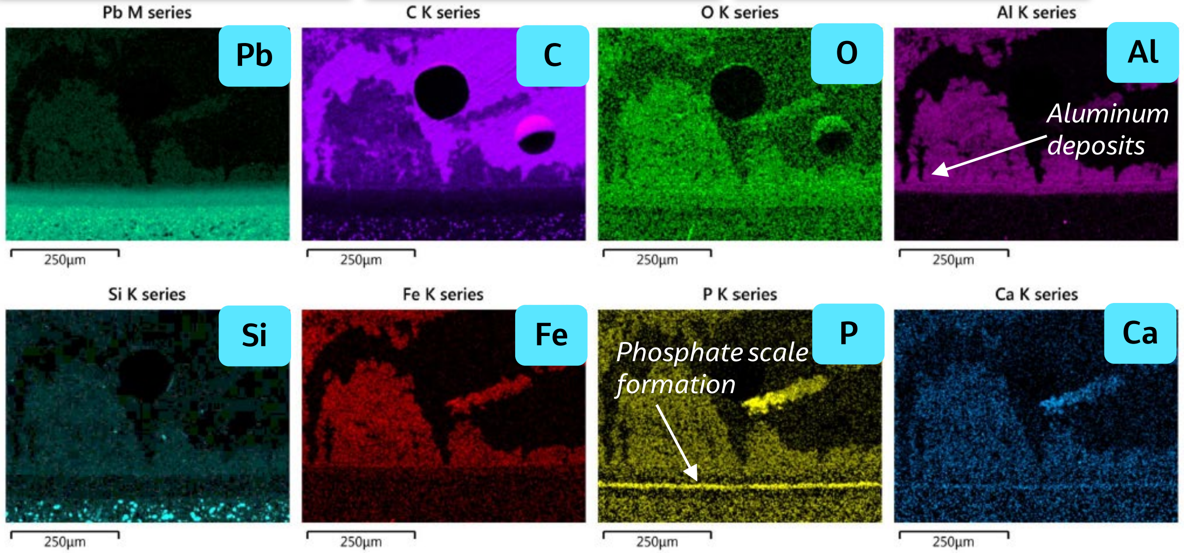
OrthoPO$_4$ has penetrated amorphous aluminum deposits to form phosphate-based lead scale at the pipe surface

SEM/EDS and XRD Scale Analysis

Windsor

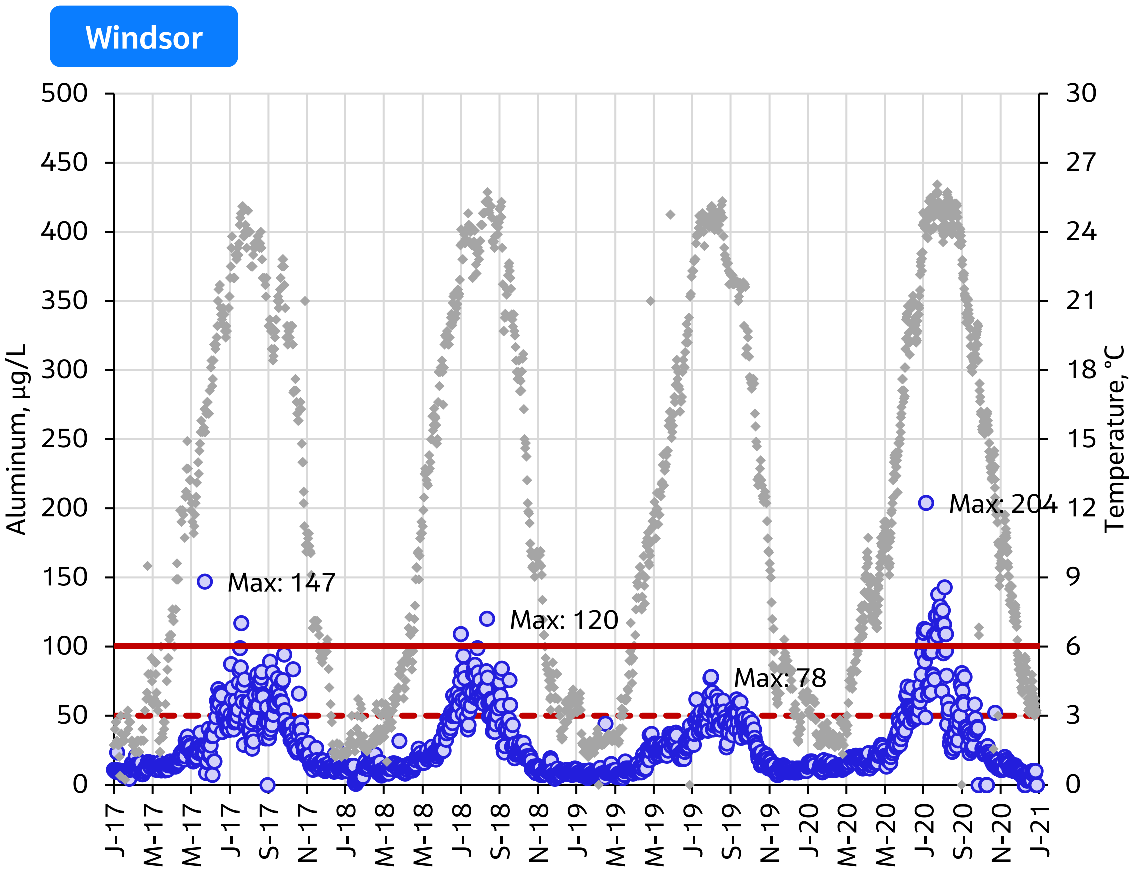


Hamilton

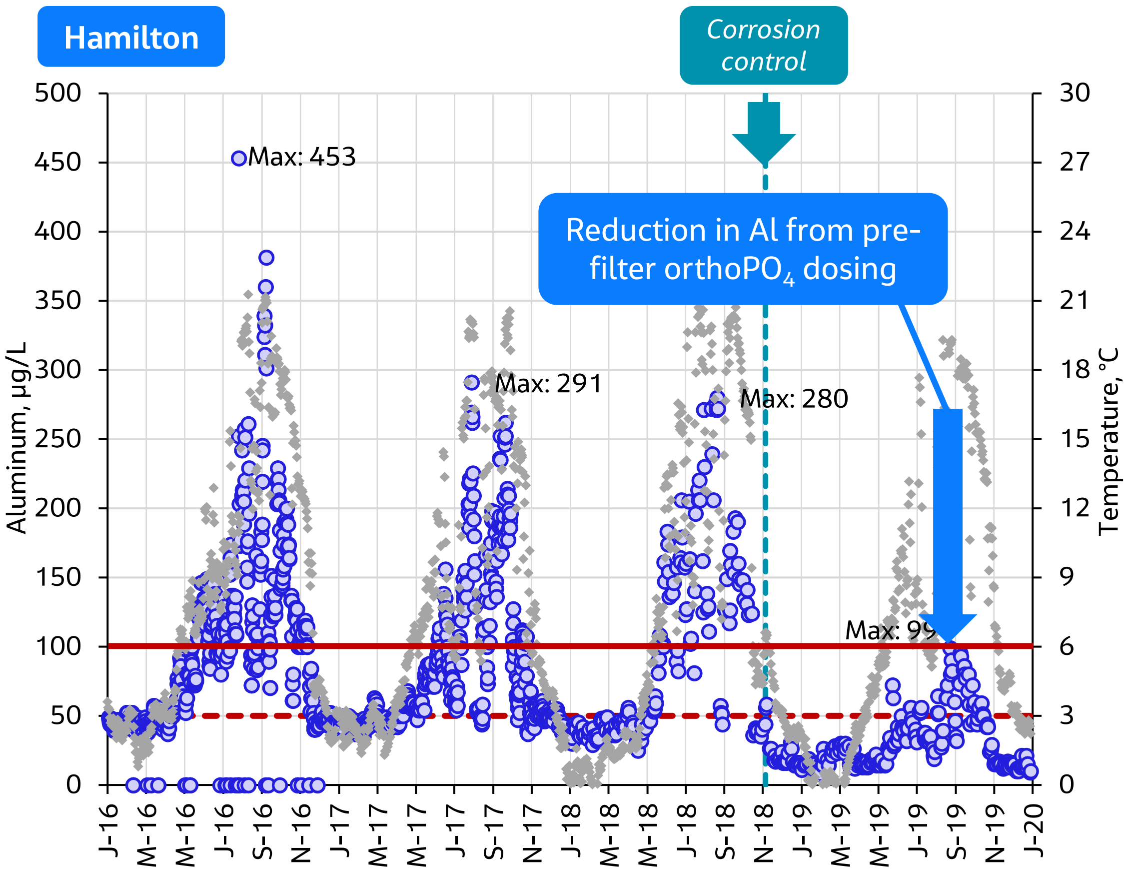


SEM/EDS = Scanning Electron Microscopy / Energy Dispersive X-Ray Spectroscopy; XRD = X-Ray Diffraction

Residual Aluminum in Treated Water



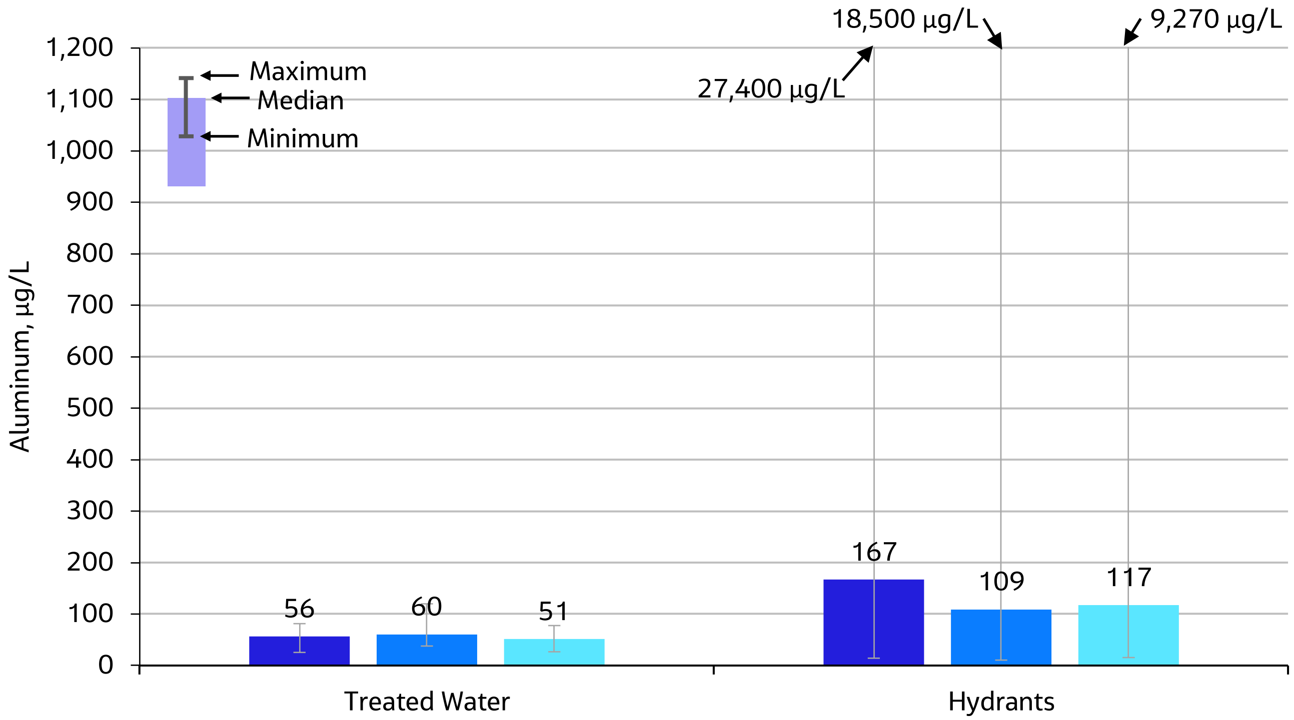
pH control with CO_2 (target 7.1)
Summer Al peaks above OG
Annual avg. Al below best practice



No pH control
Pre-CC: Summer Al peaks well above OG,
annual avg. Al above best practice but below OG
Post-CC: Summer Al peaks around OG, annual avg. Al below best practice

Aluminum in Hydrants and Residential Samples – Windsor

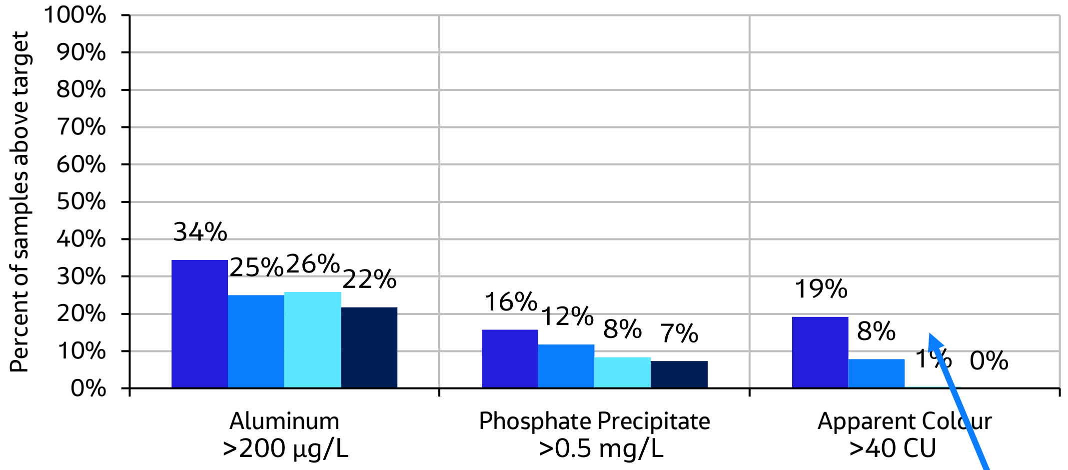
Median, Min, and Max Aluminum – Summer Sampling Rounds



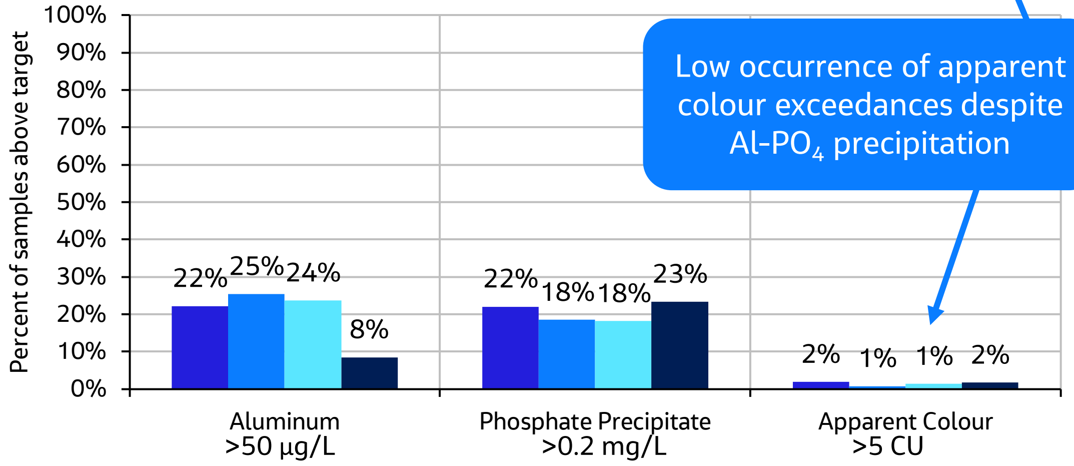
Significant accumulation and release of aluminum can occur even with treated water aluminum below OG – important to monitor
Aluminum-phosphate precipitation was observed but did not result in widespread aesthetic impact like that observed in Washington DC

2017
2018
2019
2020

Percent of Samples Above Target – Hydrants

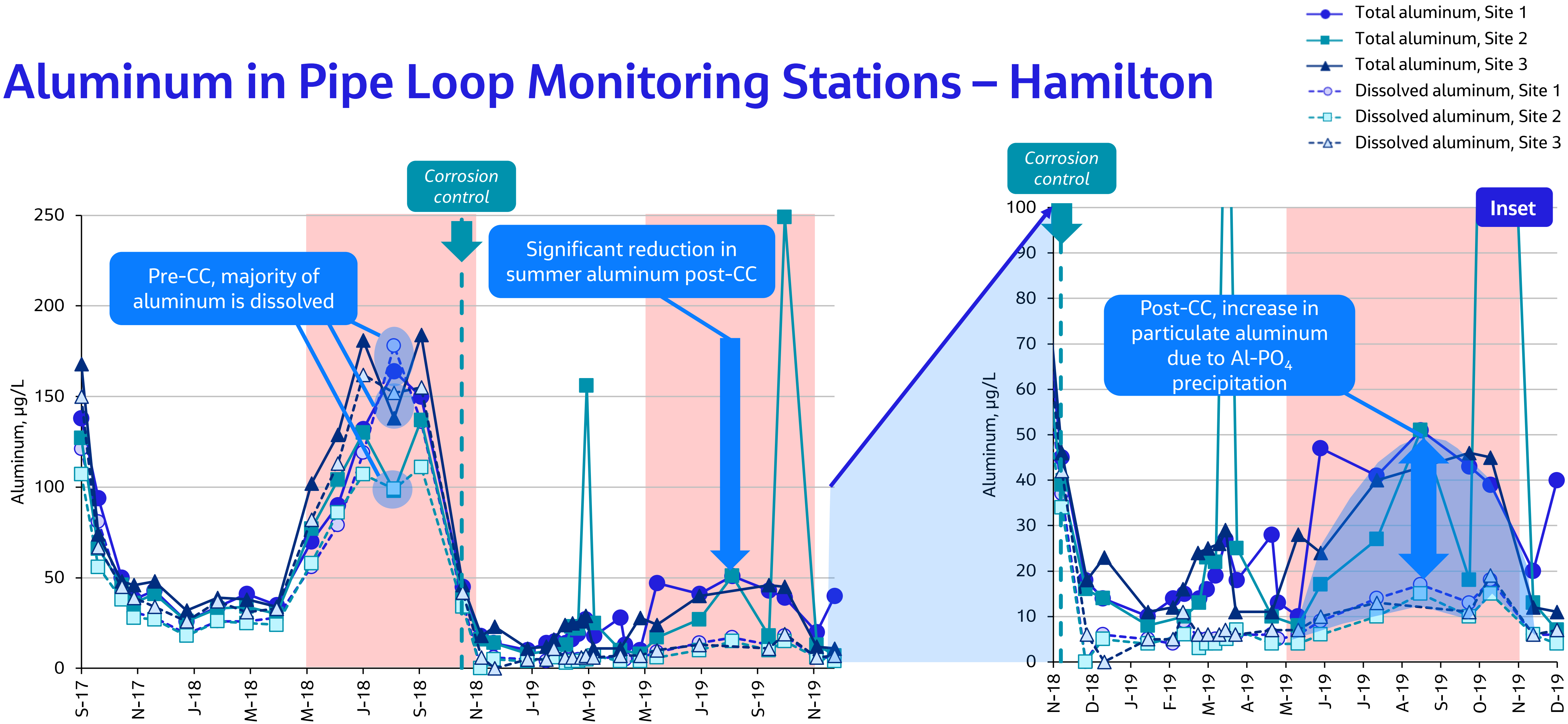


Percent of Samples Above Target – Residential Samples



Low occurrence of apparent colour exceedances despite Al-PO_4 precipitation

Aluminum in Pipe Loop Monitoring Stations – Hamilton



Prior to corrosion control, majority of aluminum in the distribution system was dissolved
Reduction in treated water Al from pre-filter orthoPO_4 dosing has helped control Al in the distribution system to ~50 µg/L during warmer months
Al precipitation is occurring and has increased post-corrosion-control and the precipitate is mobile

Proactive Flushing

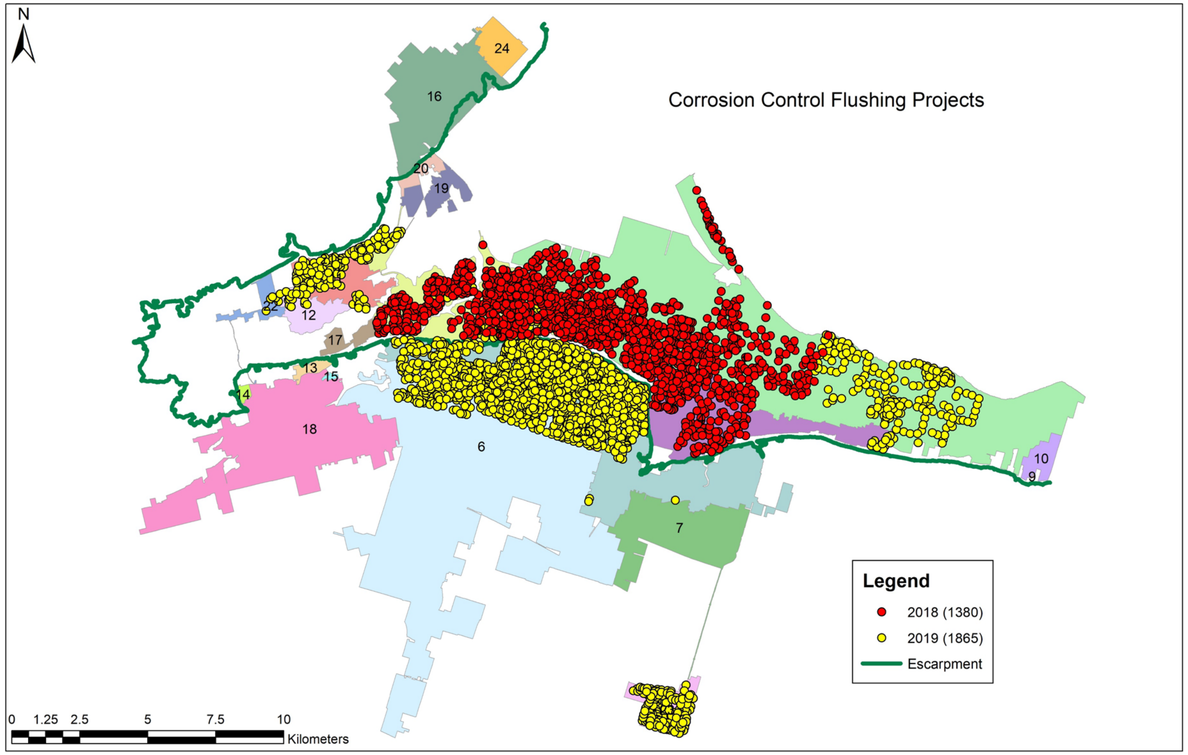
Windsor

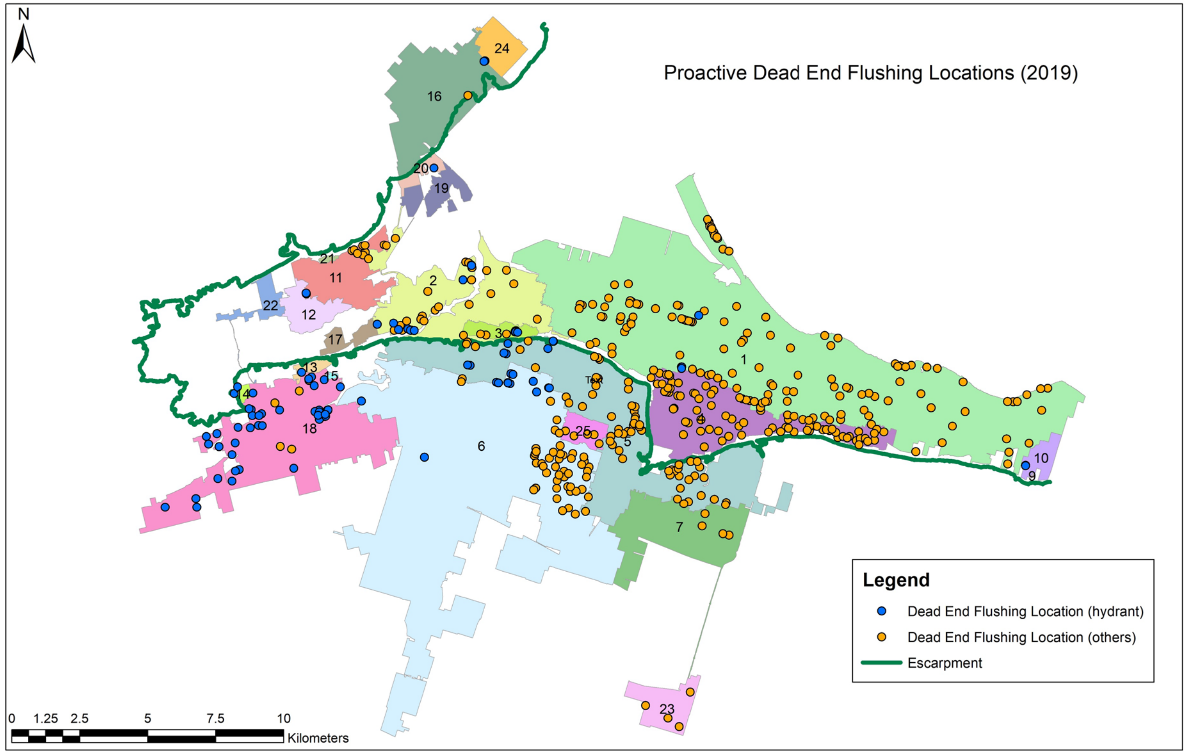
Dead-end flushing
Conventional flushing (fire-flow testing)

Hamilton

Dead-end flushing
Conventional flushing (fire-flow testing)
UDF + quasi-UDF (corrosion control)

Hamilton





Flushing has helped to remove accumulated aluminum, spread orthoPO_4, and maintain chlorine residual by temporarily reducing water age

Summary

Key Takeaways

Summary

- **Residual aluminum** in treated water from the use of **aluminum-based coagulants** can **accumulate in distribution systems**, potentially impacting hydraulics, water quality, secondary disinfection, & corrosion control

- **Coagulation optimization** can reduce residual dissolved aluminum in treated water

- Two systems with **legacy aluminum** implemented **phosphate-based corrosion control**
  - An initial orthophosphate dose of **2 mg/L as PO_4** was applied in anticipation of potential **aesthetic impacts** caused by the precipitation of aluminum with orthoPO_4 above 3 mg/L as PO_4
  - In the absence of pH control at their WTP, Hamilton utilized **pre-filter orthoPO_4 dosing** to precipitate and remove aluminum in the treatment process, **preventing it from entering the distribution system**
  - **Rapid lead reduction** was observed at 2 mg/L as PO_4 with gradual reduction ongoing
  - **Aluminum-based amorphous deposits** were confirmed to be present in lead service lines, but scale analysis confirmed that orthoPO4 had penetrated these amorphous deposits, forming **phosphate-based scale at the pipe surface**
  - Despite evidence of aluminum-phosphate precipitation, **no widespread "milky water" aesthetic impact** was observed in either system, due to the lower initial orthophosphate dose and control of treated water aluminum to <100 µg/L
  - **Distribution system water quality monitoring** and **flushing** were key strategies used to proactively manage aluminum-phosphate precipitation

Acknowledgements

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Thank You!

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