Managing Manganese in Distribution Systems

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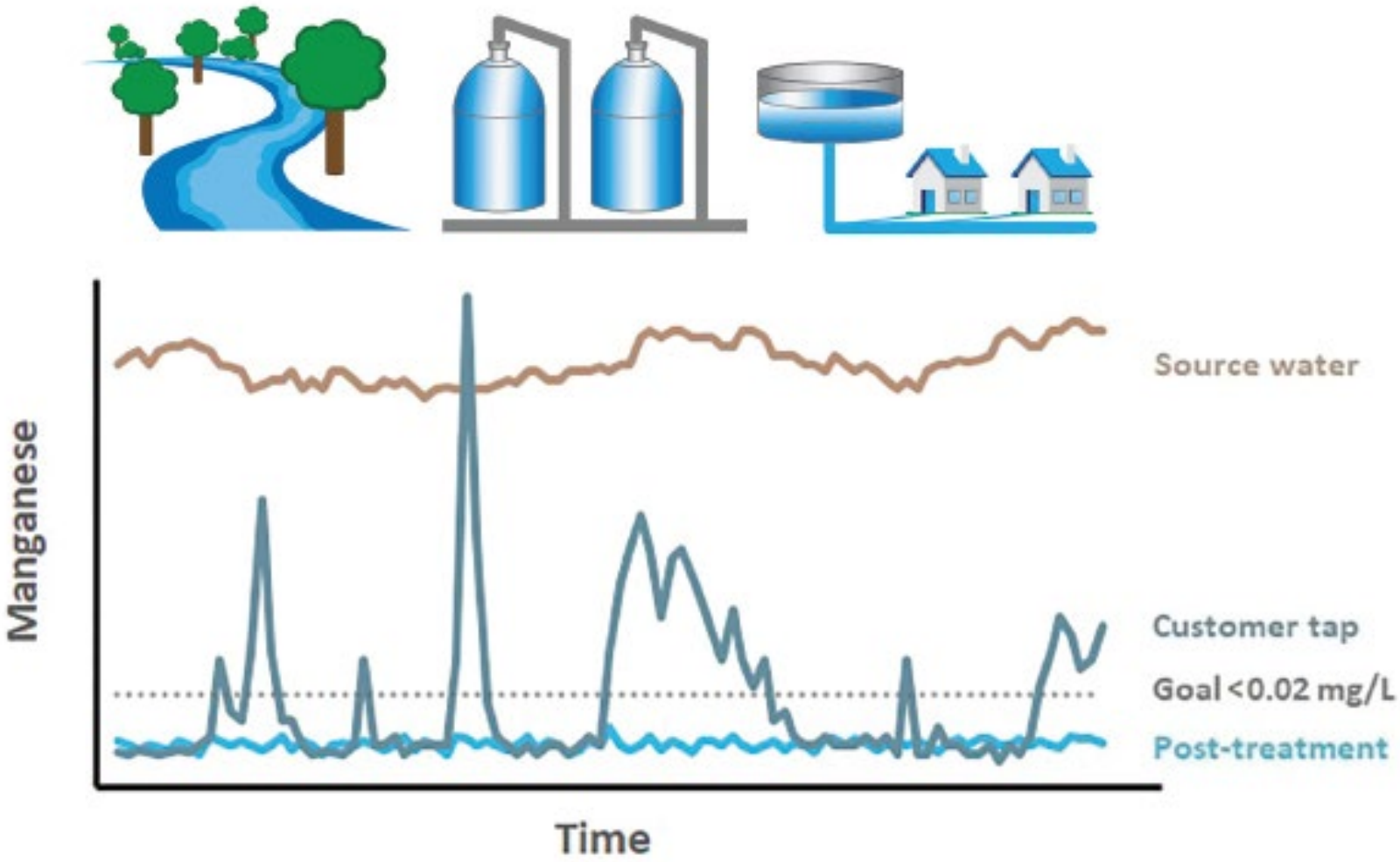
Overview and Purpose

- Manganese (Mn) deposit accumulation and release within the distribution system
- Water chemistry factors that affect stability of legacy Mn deposits
- Guidance for utilities to assess and mitigate legacy Mn risks

Distribution Systems are Reactors

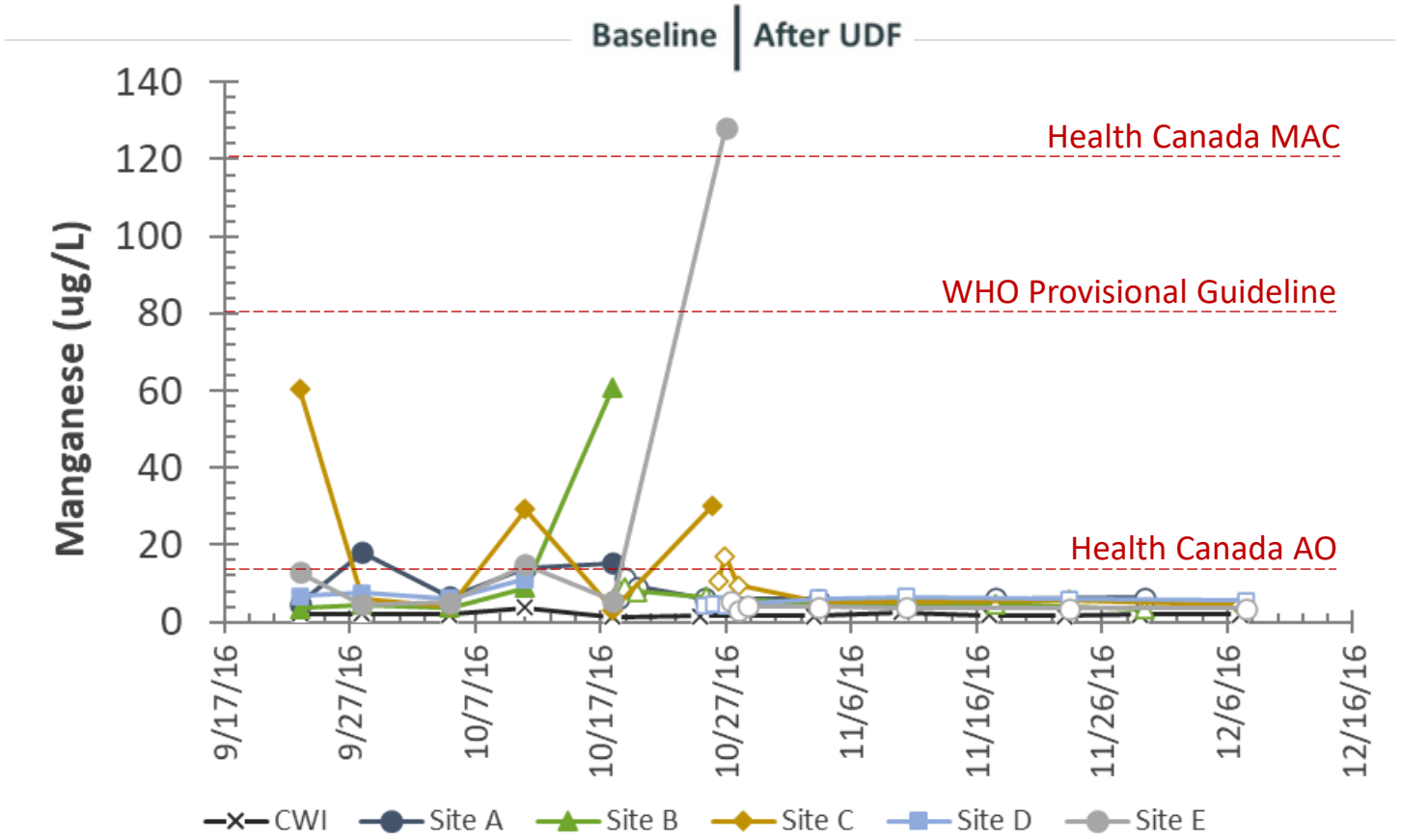
- Pipes act as accumulation “sinks” for Mn and other metals
  - MnOx coats pipe walls… and then attracts more Mn
- Accumulated Mn deposits can be re-mobilized (released)
  - Changes in water chemistry or flow hydraulics
  - [Mn] at the tap ≠ [Mn] at entry-points

Accumulation and Release



Releases Occur Under Routine Conditions

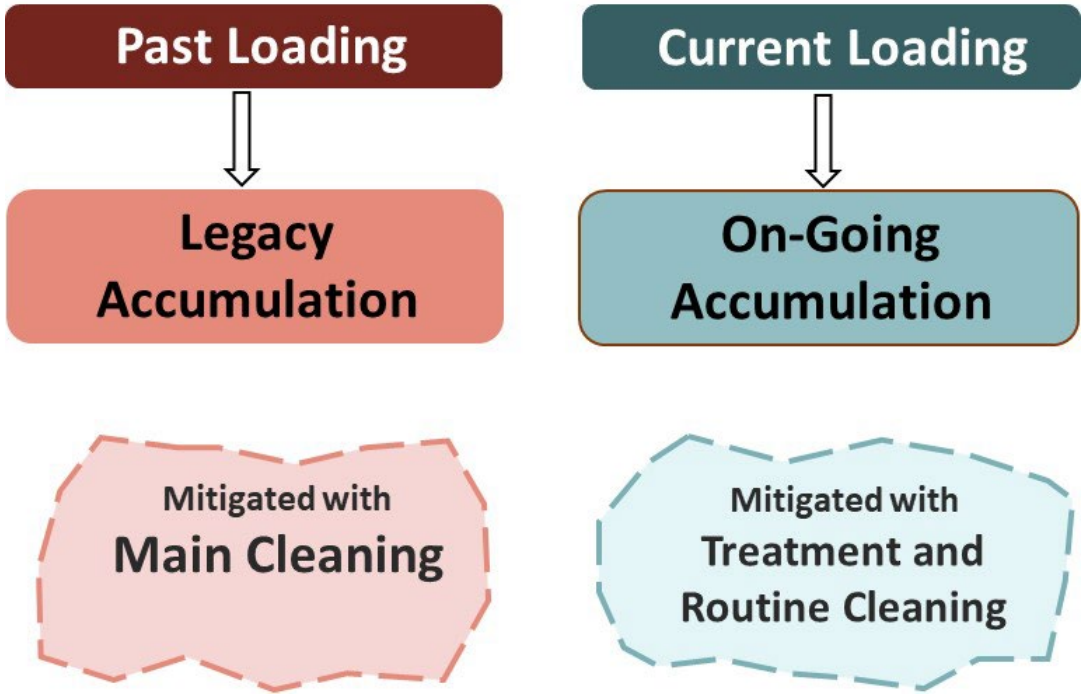
- Due to dynamic hydraulics of distribution systems
- Difficult to anticipate
- Usually go un-detected
- Routine unidirectional flushing (UDF) can prevent “hydraulic releases”



Source: Hill et al. 2018 (WRF 4653)

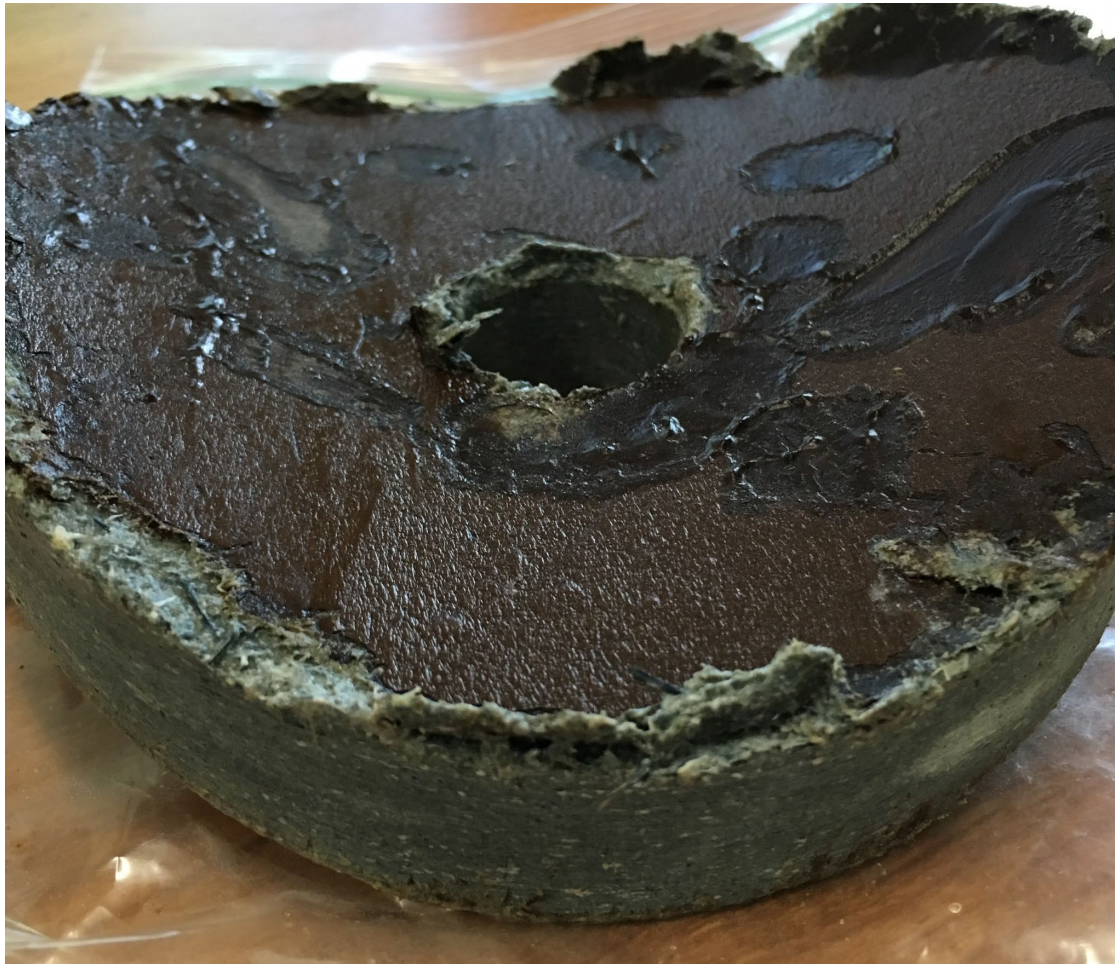
Legacy Manganese

- Legacy Mn exists in all systems
- Accumulation ~ Loading x Time
  - Mn Secondary MCL (0.05 mg/L) supports accelerated accumulation
  - Industry guidance: Mn < 0.02 mg/L
  - Even low or “non-detect” loading can be problematic over long timeframes
- For problem sources, treatment to reduce Mn loading is vital but does not address legacy Mn



Legacy Mn in Distribution Systems

C900 PVC Pipe
Calif. system



Asbestos Cement Pipe
Utah system

Legacy Mn in Distribution Systems

Unlined Cast Iron Pipe
Idaho system

Cement-Lined Ductile Iron Pipe
Utah system

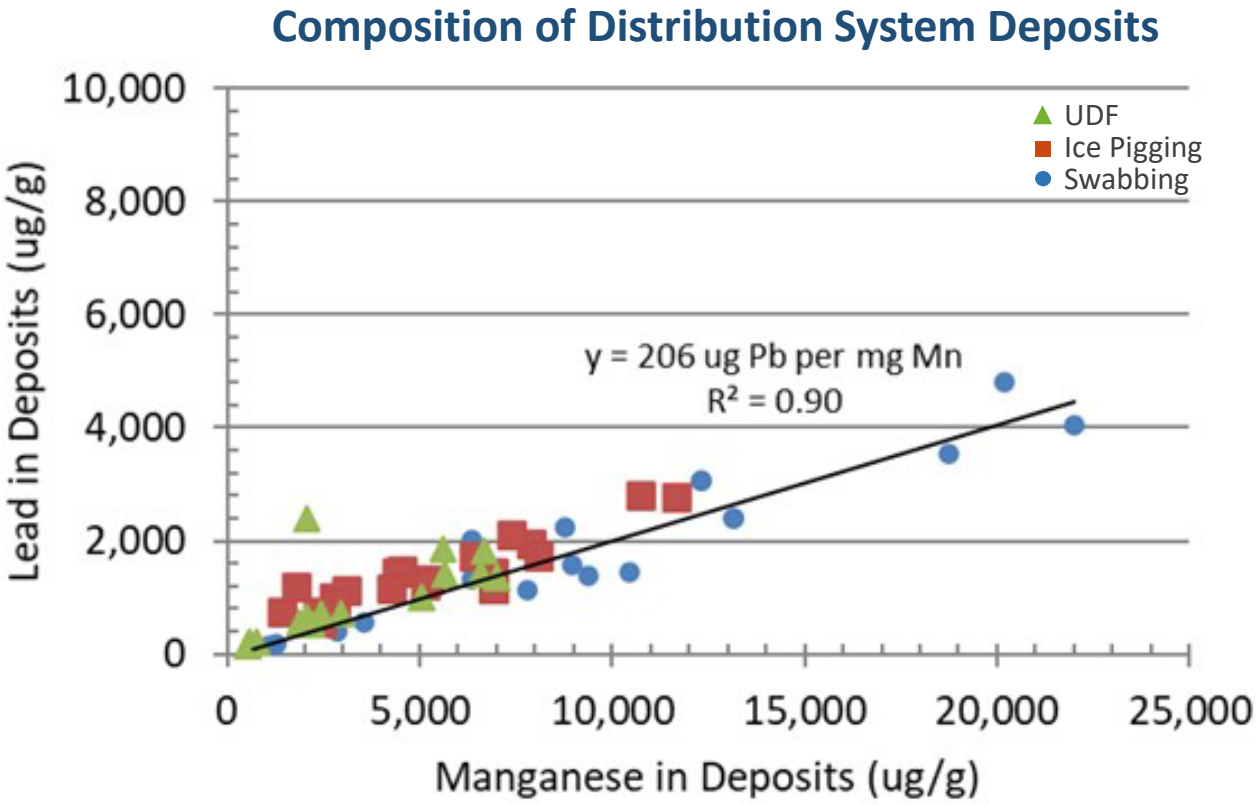
Mn Accumulation in Premise Plumbing

In-house “flushing” to remove Mn from residential plumbing

Source: Confluence Engineering Group LLC

Co-Accumulation of Heavy Metals

- MnOx solids have tremendous adsorptive capacity for heavy metals
  - Most notably, lead (Pb^{2+})
  - Mn scavenges “non-detect” Pb present in source water
- Comparative adsorptive capacities
  - Pb:Mn ~ 10-100 ug/mg
  - As:Fe ~ 1-10 ug/mg
- Co-release or desorption
  - Mn releases of ~ 0.05 mg/L can cause Pb ~ 0.01 mg/L



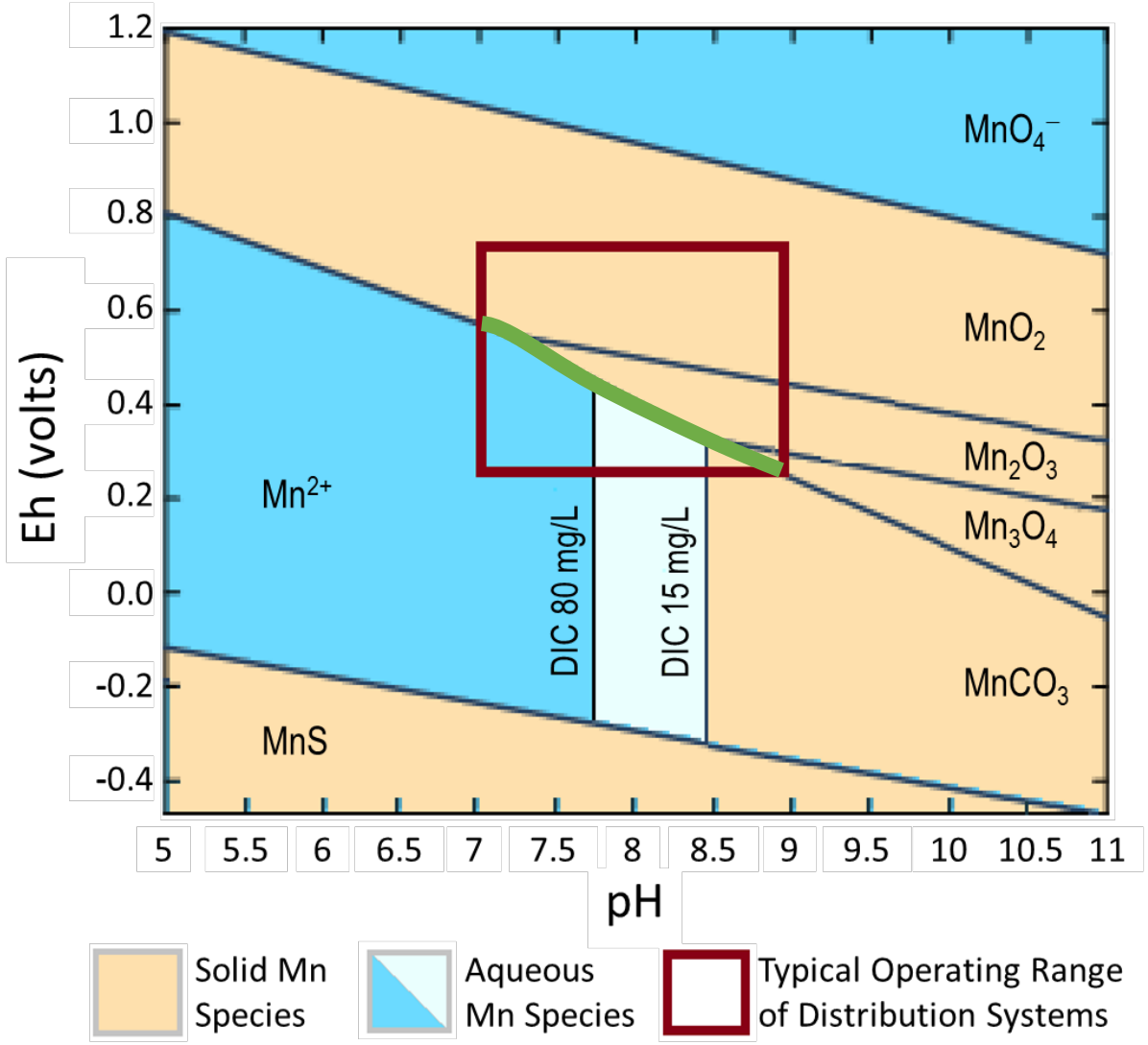
Source: Friedman, Hill, et al. 2016 (WRF #4509)

Manganese Release Mechanisms

	Hydraulic	Chemical
Form of Mn Released	**Particulate solids** Discolored water might help signal an upset to customers	**Soluble or mixed-phase** Less color per mg/L of Mn released (higher risk of exposure)
Typical Scope of Impact	**Fairly localized** **Short-lived** Mitigated with flushing	**More widespread** **Prolonged** Can last several weeks or months Difficult to mitigate

Legacy Mn + Chemistry Change = Re-Equilibration

- Leads to Destabilization
- Primary Chemistry Risks
  - Δ ORP (critical Eh ~ 0.4 V)
  - ↓ pH (by ~0.3-0.5 or more)
- Other Factors (empirical)
  - ↓ DIC
  - ↑ Sulfate



Source: Hill and Lemieux, 2022

Events that Risk Mn Destabilization

- Introducing a new source
- Seasonal use of dissimilar sources (e.g., SW ↔ GW)
- Change in disinfectant type or residual concentration (↑ or ↓)
  - Converting secondary disinfectant
  - First-time introducing secondary disinfection
  - Drop or boost in chlorine residual
- Treatment change or chemical process upset
- Variability in source water pH
- Nitrification, especially in poorly buffered waters

Mn Destabilization Event in Woodland, CA

- Groundwater-only system until mid-2016
  - **100+ years of groundwater supply**
  - **Mn was ≤ 0.02 mg/L in all wells**
- Proactively conducted system-wide UDF and NO-DES to prepare the distribution system
- Introduced treated Sacramento River water in June 2016
  - Large drop in DIC and mineral content
  - Sharp increase in Cl_2 Residual (SWTR)
    - POE: 0.2 mg/L → 1.1 mg/L
    - Dist. System: 0.1-0.2 mg/L → 0.5-1.0 mg/L
- Starting about 2 weeks after surface water introduction…

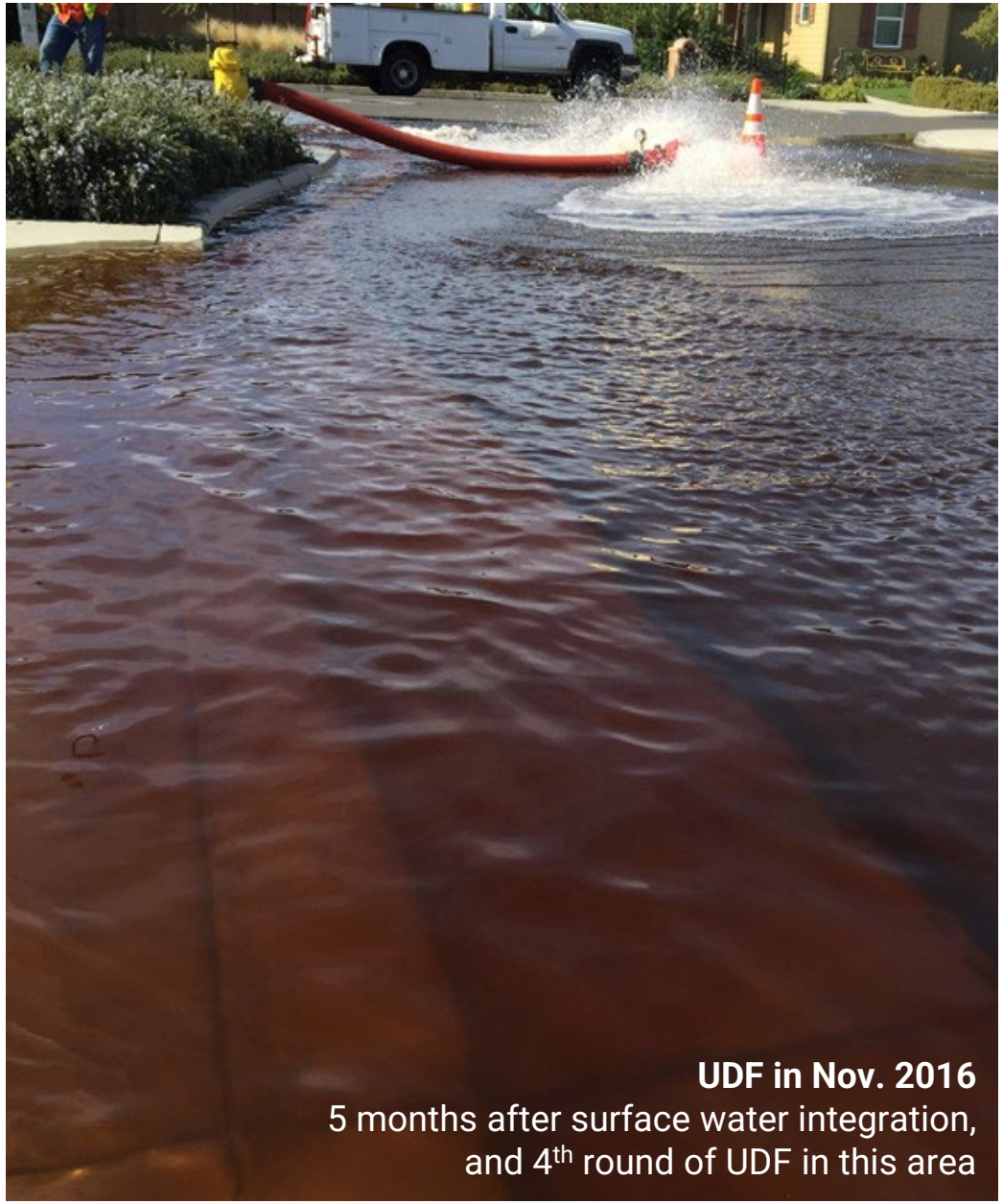
Destabilization Event (continued)

- Widespread, frequent discolored water episodes and complaints
  - Mn often ≥ 0.1 mg/L at customer taps (sometimes ≥ 1 mg/L)
  - Dissolved and particulate forms
- Caused by chemical destabilization and dissolution of legacy Mn films

Source: Customer video posted on City's Facebook page

Destabilization Event (continued)

- Upset lasted 12 months despite extensive mitigation efforts
- Repeat UDF was inadequate to control the problem (but helped accelerate recovery)
- Aggressive cleaning with foam swabbing was needed in certain neighborhoods



UDF in Nov. 2016
5 months after surface water integration, and 4th round of UDF in this area

Source: Confluence Engineering Group LLC

Assessment and Control Strategies

- **Evaluate Mn accumulation and release risk**
  - Utility self-assessment desktop tool in WRF #4314
  - Collect and analyze pipe deposits
  - Perform “event-based” distribution system water quality monitoring

Before making source, treatment, or disinfection changes, conduct pilot tests with native pipes to assess Mn scale response

- **Reduce Mn loading with treatment**
  - **“An ounce of prevention…”**
  - **Mn < 0.02 mg/L**

- **Stabilize system chemistry**
  - **Maintain adequate disinfectant residual**
  - **Blend or isolate dissimilar sources**

- **Main cleaning to remove legacy Mn**
  - **UDF (or NO-DES)**
  - **Aggressive cleaning**
    - **Foam swabbing**
    - **Ice pigging**

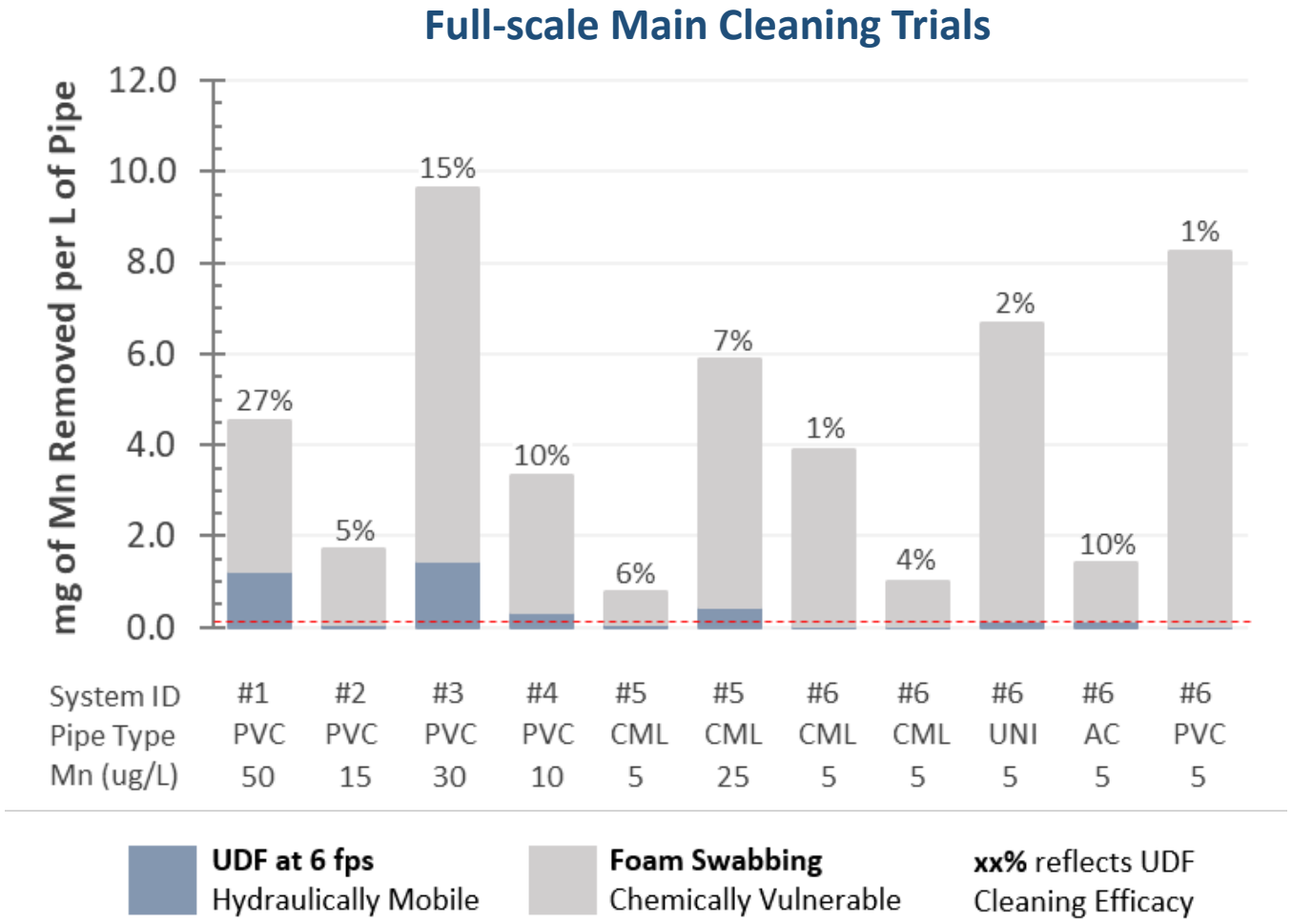
Foam Swabbing

Source: Confluence Engineering Group LLC

Challenges Flushing Legacy Mn

Sequential application of UDF (bottom) followed by foam swabbing (top) on a 1,600-ft run of C900 pipe.

Source: Confluence Engineering Group LLC



Source: Hill and Lemieux, 2022

Control Strategies for Legacy Mn

Strategy	Recommended Best Use
UDF (or NO-DES)	• **Routine practice** to prevent hydraulic releases and reduce overall rate of Mn accumulation
Aggressive Cleaning (Ice Pigging / Foam Swabbing)	• **Special or infrequent practice** to prevent or halt chemical release events, and to address problem areas where UDF has been inadequate
Stabilize Water Chemistry	• **Where feasible** • Especially important in problem areas where aggressive cleaning cannot readily be performed

Manganese is Relentless

- Mn accumulates at all concentrations (SMCL is inadequate)
- It never stops accumulating, even after treatment
- It co-accumulates and co-releases heavy metals
- Legacy Mn doesn't "go away" on its own
- It's difficult to effectively flush off pipes
- It's sensitive to changes in water chemistry
- Releases can cause Mn and other metals to exceed health-based levels at the tap with or without discoloration

Utilities should develop a source-to-tap plan to continuously control Mn accumulation

Thank You!

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